Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

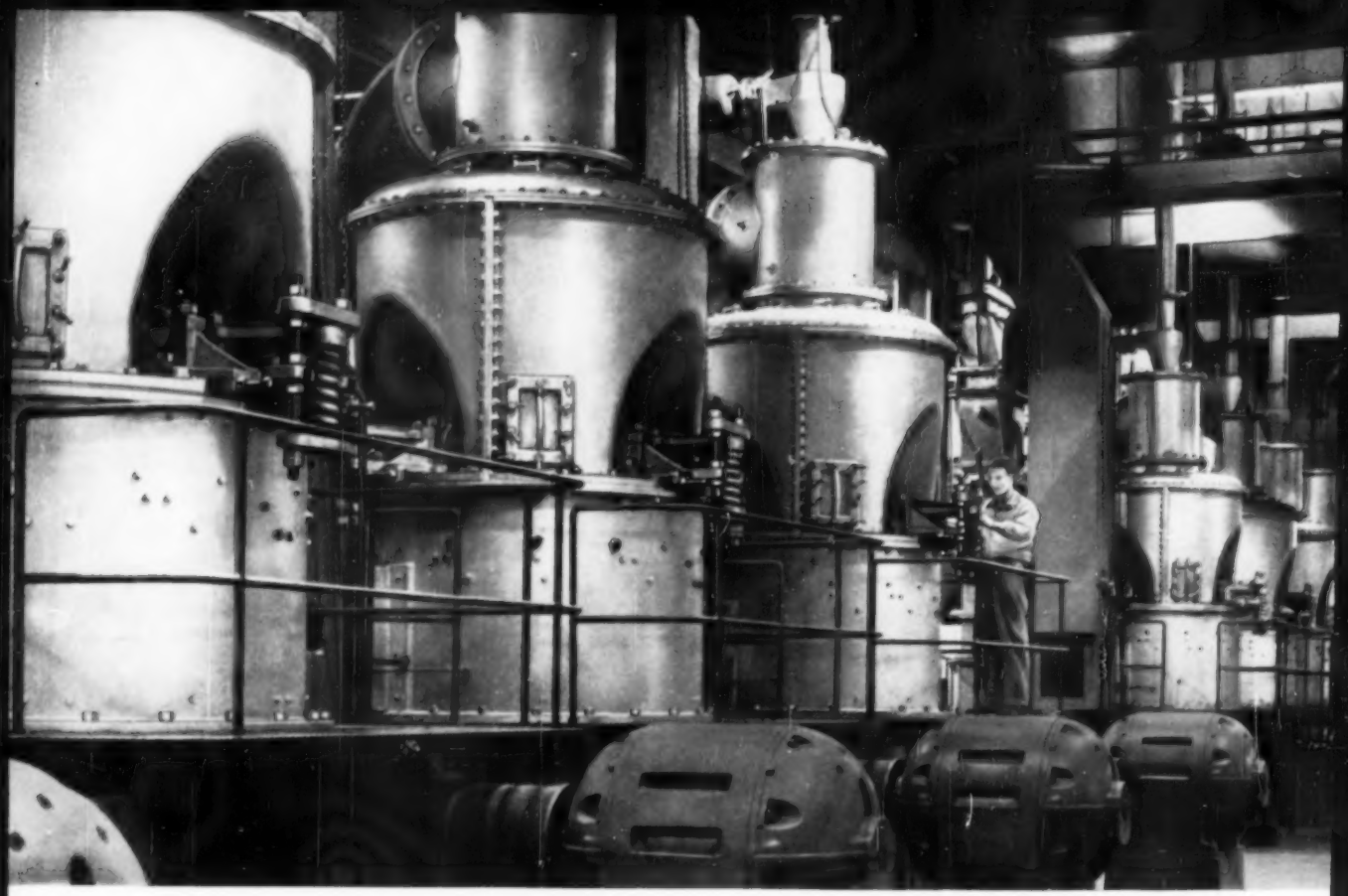
August 1960

Direct Energy Conversion

Peaking Instrumentation

Generator Shutdown Economics

The Invisible Stack



Any coal is grist for the Bowl Mill

. . . it grinds fine, fast—and efficiently

Lignite in Spain . . . semi-bituminous in Holland . . . Petroleum coke in Indiana . . . C-E Raymond Bowl Mills pulverize just about every type of coal to feed boilers in power plants all over the world.

Here are nine important reasons why C-E Raymond Bowl Mills have become the international standard of the utility industry:

1. Handles High Moisture Fuels—Even lignite with 50% moisture is thoroughly dried because the Bowl Mill premixes raw coal with the dried product in an atmosphere up to 700 F air;

2. Low Power Consumption—Low weight of grinding elements, rapid flow of coal through mill, fast drying and prompt removal of fines all combine to assure minimum power use;

3. Reduces Sulphur in Flue Gas—Because the mill rejects a substantial amount of pyrites, sulphur content of flue gas is materially reduced;

4. Continuous Service—No metal-to-metal contact between rings and rolls minimizes wear. Continuous operation for as long as 20,000 hours is not uncommon;

5. Low Maintenance—Uninterrupted service means lower maintenance. Outage time is minimized because of ease with which mill can be taken apart and reassembled;

6. Fineness Control—Necessary adjustments to change fineness are made externally. No need to stop the mill;

7. Automatic Grinding Adjustment—Spring-loaded journals compensate instantaneouly and automatically for variations in fuel;

8. Infrequent Lubrication—When lubrication is required, it can be done externally, without taking the mill out of service;

9. Vibrationless—Quiet—Lack of metal-to-metal contact between grinding elements assures quiet, vibrationless operation.

The Bowl Mill is a result of Creative Engineering—the *C-E* approach to providing advanced design boilers and fuel burning equipment for all fuels and steam requirements. If pulverizers are included in your present or future expansion programs, why not investigate the Bowl Mill more fully? Our Catalog PC-8 gives detailed information.

COMBUSTION C-E ENGINEERING

General Offices: Windsor, Conn. • New York Offices: 200 Madison Avenue, New York 16

C-274A

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Combustion

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

volume 32 number 2 **August 1960**

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COVER PHOTO

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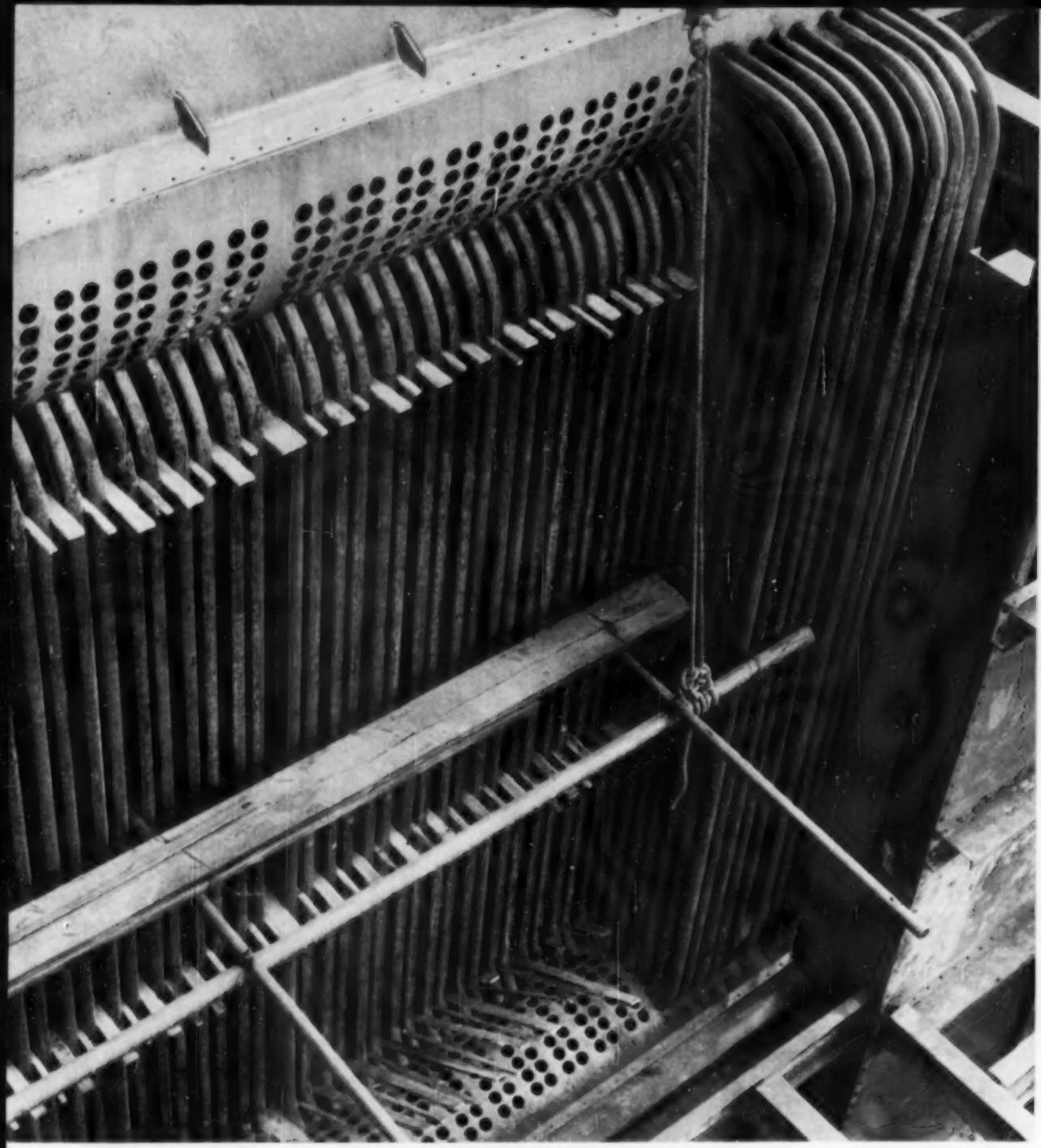


REPUBLIC ELECTRUNITE BOILER TUBES are produced from highest quality flat rolled open-hearth steel and manufactured by Republic's exclusive process that ELECTRically-UNITEs the tube under pressure without additional foreign or extra metal. Each length of ELECTRUNITE is hydrostatically or electronically tested to conform with applicable ASTM specifications, and the ASME Boiler and Pressure Code. ELECTRUNITE is specified for the big jobs because dependability is built-in. The ELECTRUNITE process assures uniform wall thickness, uniform ductility, uniform diameter, and true concentricity. Bends are smooth and uniform. Rolling-in operations are easier.

POWER FOR PAPER MAKING...

with REPUBLIC ELECTRUNITE BOILER TUBES

Continuous, dependable power is one of the first requirements in paper making. That is why Republic ELECTRUNITE Boiler Tubes are on the job in the new boiler plant of the West Virginia Pulp and Paper Company, Covington, Virginia.

Erie City Iron Works, Erie, Pennsylvania, were designers, engineers, and erectors of the unit, producing 77,900 pounds per hour at a normal operating pressure of 170 pounds. Waste black liquor from digestion of pulpwood is burned in a rotary incinerator and the hot gases are fed into the boiler, producing steam, the power for paper making.

ELECTRUNITE is produced by an exclusive process universally accepted by leading technical authorities, code societies, boiler and heat exchanger manufacturers, Federal and State committees, and boiler insurance requirements.

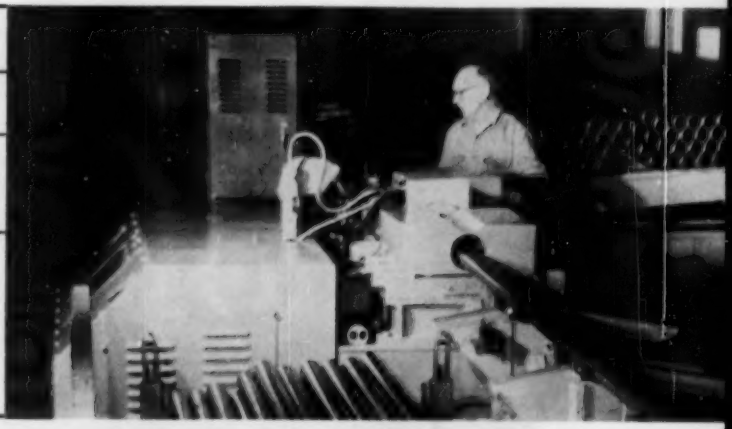
Full normalizing, uniform wall thickness, diameter, true concentricity, assure easy workability and inservice dependability. Bends are smooth, uniform. Rolling-in operations are easier.

To learn how ELECTRUNITE can offer you greater savings in installation time and operating costs, call your Republic Representative. Or write.

FARROWTEST REJECT TABLE

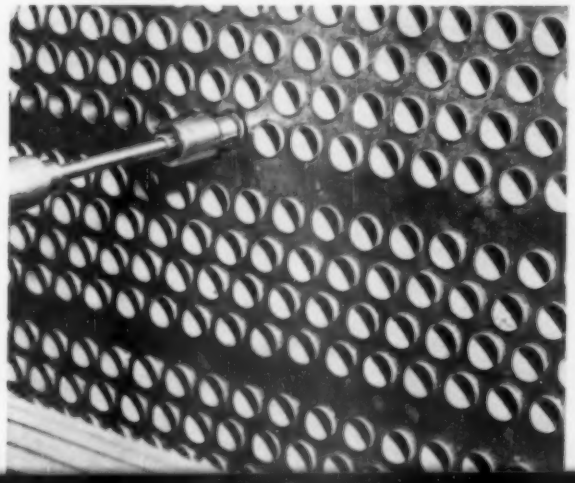
Wall Thickness (B.W. Gage)	Minor Dimension of Defect (Length or Depth)	Defective Area (Length, Depth Plane)
20	0.006 IN.	0.0025 Square Inches
18	0.006 IN.	0.003 Square Inches
16	12.5% of Wall	0.003 Square Inches
14 and 13	12.5% of Wall	0.004 Square Inches
12 and Heavier	12.5% of Wall	0.005 Square Inches

FARROWTEST detects and rejects not only tubing containing defects which completely penetrate the wall; but also tubing with defects equal to, or greater than, those shown in this table. For irregular defect shapes, a tube with defect area equal to or greater than shown above is rejectable. Where required, sensitivity of FARROWTEST equipment can be calibrated to reject defects of lesser specified area than shown in table, at extra cost.



FARROWTEST—QUALITY YOU CAN MEASURE. Not a laboratory theory, not a mere inspection tool, but an exclusive production test that detects and rejects tubing containing defects of critical size. FARROWTEST is offered as an alternative to other less positive tests in accordance with the table above, at no extra cost.

REPUBLIC ELECTRUNITE STAINLESS STEEL TUBING resists corrosion and provides long trouble-free service in heat exchanger, condenser, evaporator operations. When water is a problem, call your Republic representative, or send coupon for additional information.



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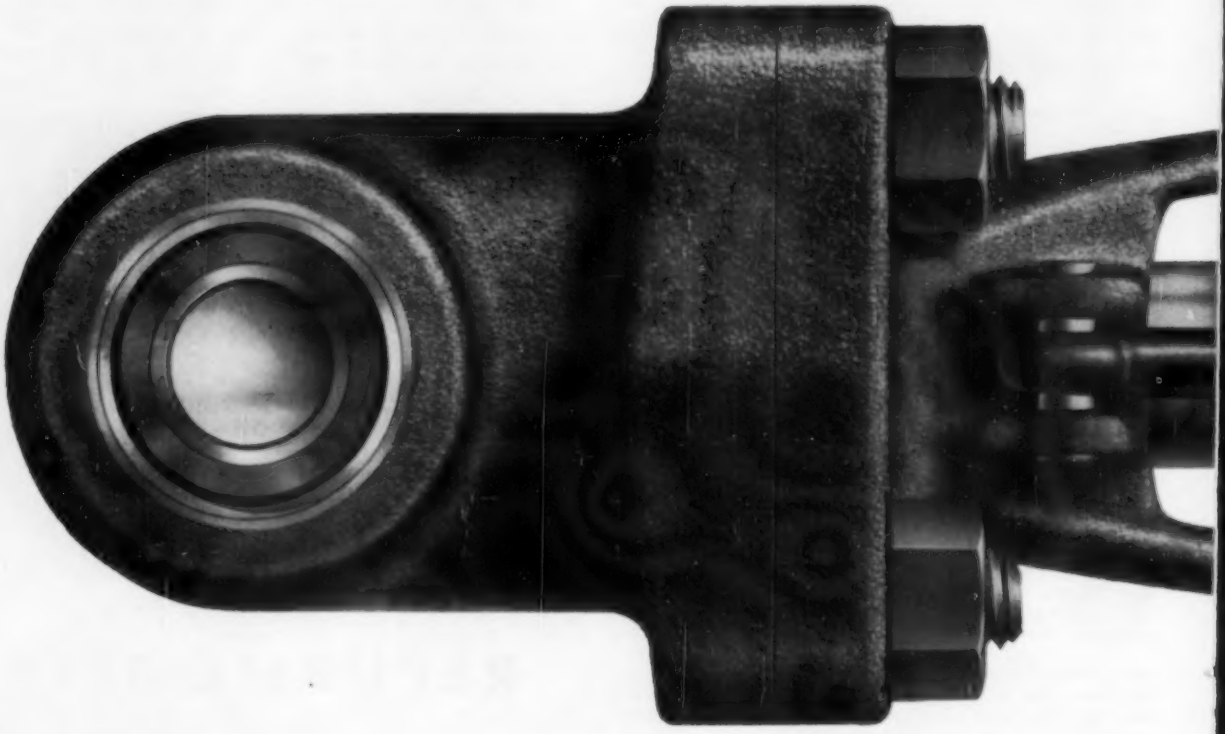
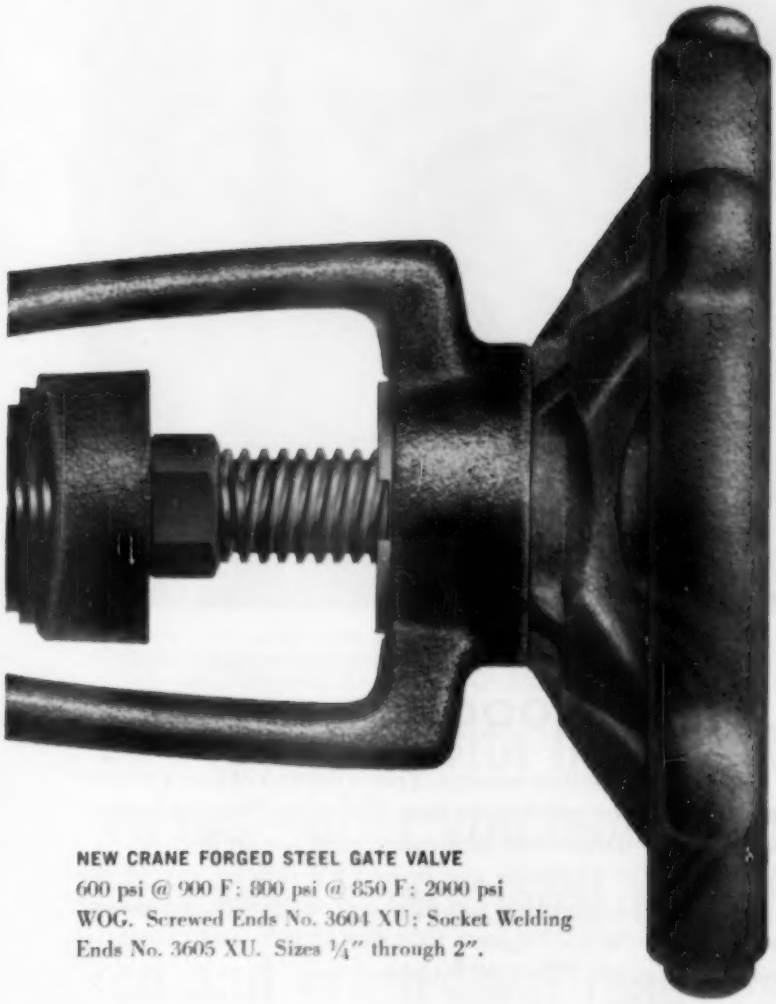


REDESIGNED!

THE NEW SMALL FORGED STEEL GATE VALVE



NEW CRANE FORGED STEEL GATE VALVE
600 psi @ 900 F; 800 psi @ 850 F; 2000 psi WOG. Screwed Ends No. 3604 XU; Socket Welding Ends No. 3605 XU. Sizes ¼" through 2".

This is a whole new valve, not just one with a new feature added. This redesign incorporates all the features you told us you wanted plus a few others we know will make this valve a better buy in terms of longer service life, less maintenance, easier and faster servicing.

Like the new "bow-leg" yoke, which for the first time gives you plenty of hand room for easy stuffing box maintenance. And like the long-life braided asbestos packing, with Inconel wire insert. The "universal" trim that can be used for either oil or steam, eliminating many of your stocking problems. The spiral wound stainless steel bonnet gasket with asbestos filler, made blowout-proof with a male-female joint.

But what we really want you to remember, more than any single feature, is that this Crane valve is the newest—all new—valve on the market . . . well worth considering when you need small, high-pressure steel gate valves. We'd like you to compare this new valve with any other comparable valve feature for feature.

Your local Crane distributor has technical literature and a complete selection of these valves right in stock. Call him on small steel gates. In fact, he's your best bet to call no matter what valve you want because he carries the broadest line of quality valves in the world.

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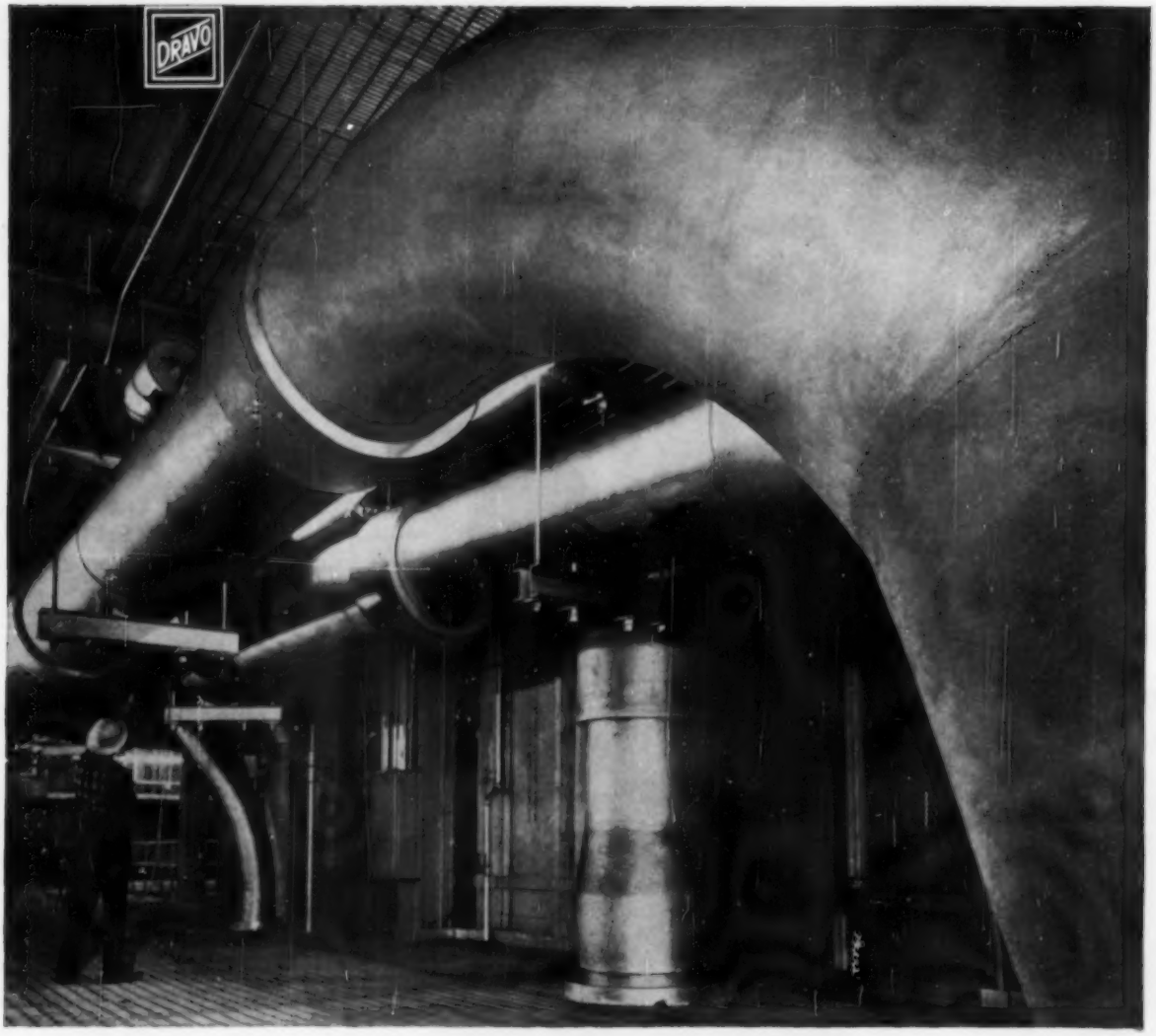


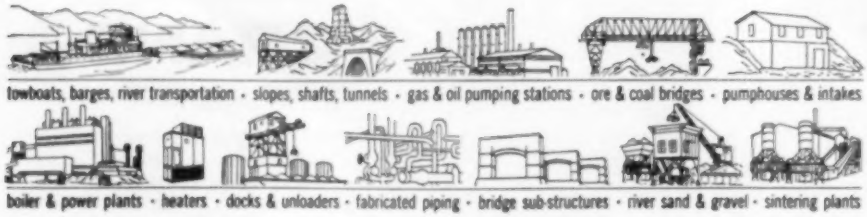
Three-inch wall main steam piping. Boiler will operate at 2400 pounds per square inch and 1050° Fahrenheit.

Race track for 227,000 horses

At Ohio Edison's new Stratton power station, high pressure, high temperature steam races through this heavy wall piping at 125 miles per hour, creating more than 227,000 horsepower in the turbine.

In addition to main steam and boiler feed lines the project included instrument piping and all auxiliary systems. This is the first of four 170,000 kw units to be installed at the Stratton station; Dravo will fabricate piping for all four.

Inquiries are invited on this or any of the engineered products and services listed below. Write DRAVO CORPORATION, PITTSBURGH 25, PENNSYLVANIA.



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COMPACT
New "Welbloc" Gage Valves permit space-saving installation.
CLEAR
Brilliant water level readings through wide ports. Steam shows red; water shows green.
CONVENIENT
Individual "package" port assemblies easily quickly replaced.

improved Yarway Color-Port Gages for medium pressure boiler service to 1050 psi*—with new "Welbloc" Gage Valves—offer you reduced maintenance, increased operational time, brilliant red and green level readings.

*High pressure design for pressures to 3000 psi also available

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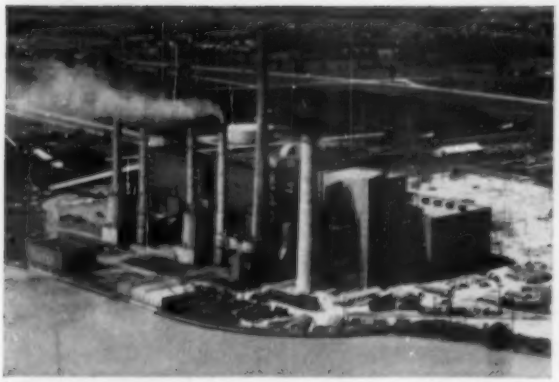
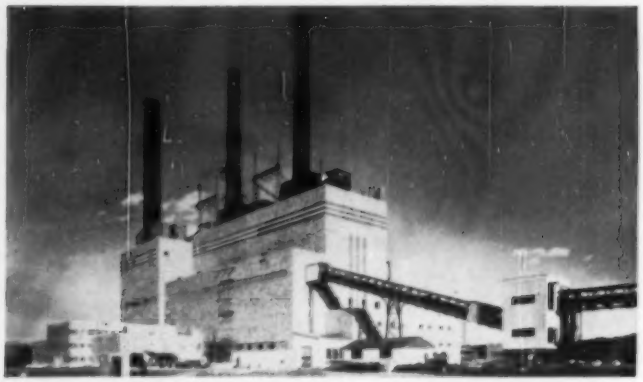
PROOF OF PERFORMANCE

FPC's list of "most finds Bailey users

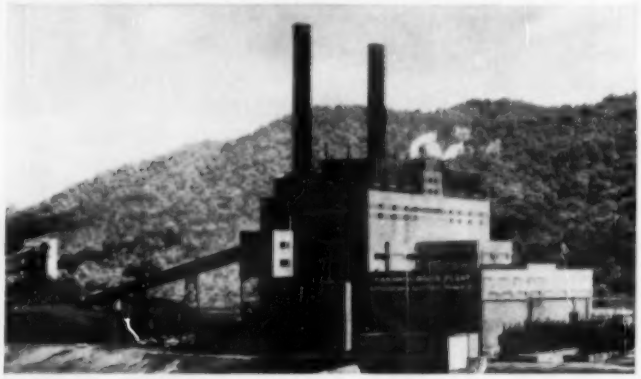


ST. CLAIR (The Detroit Edison Co.)—top 11, 1954-1958, averaging 9222 Btu/kwhr.

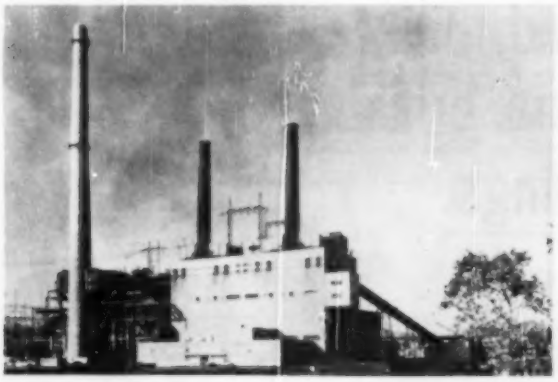


TANNER'S CREEK (Indiana & Michigan Electric Co.)—top nine, 1954-1958, first in 1956, averaging 9204 Btu/kwhr.

KYGER CREEK (Ohio Valley Electric Corp.)—top six, 1955-1958, first in 1955, averaging 9164 Btu/kwhr.



KANAWHA RIVER (Appalachian Power Co.)—top three, 1954-1958, first in 1954 and 1957, averaging 9128 Btu/kwhr.



MUSKINGUM RIVER (Ohio Power Company)—top five, 1954-1958, averaging 9216 Btu/kwhr.

BAY SHORE (The Toledo Edison Co.)—top ten, 1956-1958, averaging 9241 Btu/kwhr.

efficient plants"
as consistent repeaters

Thirteen of the 15 most efficient power plants on the Federal Power Commission's 1958 list use Bailey Meters and Controls.

For most of these plants, this marks the fourth or fifth consecutive year of top-ranked operating economy.

It is significant to engineers responsible for steam plant design and operation, that so many of these top performing plants are using Bailey Meters, Combustion Controls, Feed Water Controls and Superheat Controls.

Today, for breadth of product line, depth of experience and leadership in practical plant automation, no one can offer more to the power industry than Bailey. To apply Bailey's capability to your specific needs, check with the Bailey District Office or Resident Engineer listed in your phone book.

A145-2

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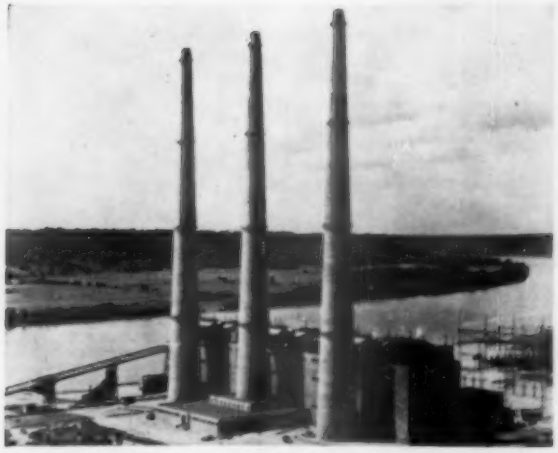
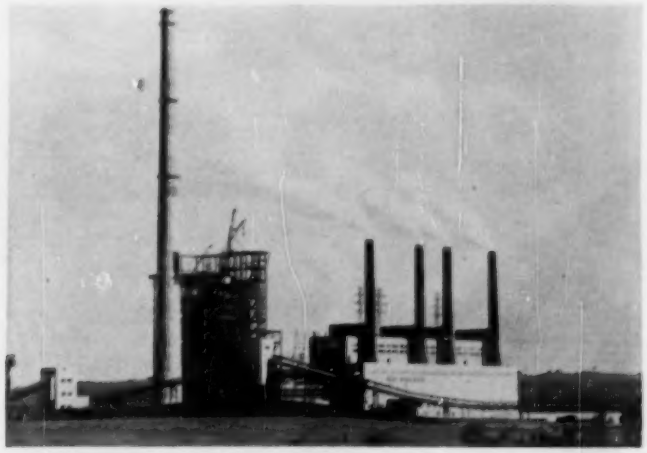
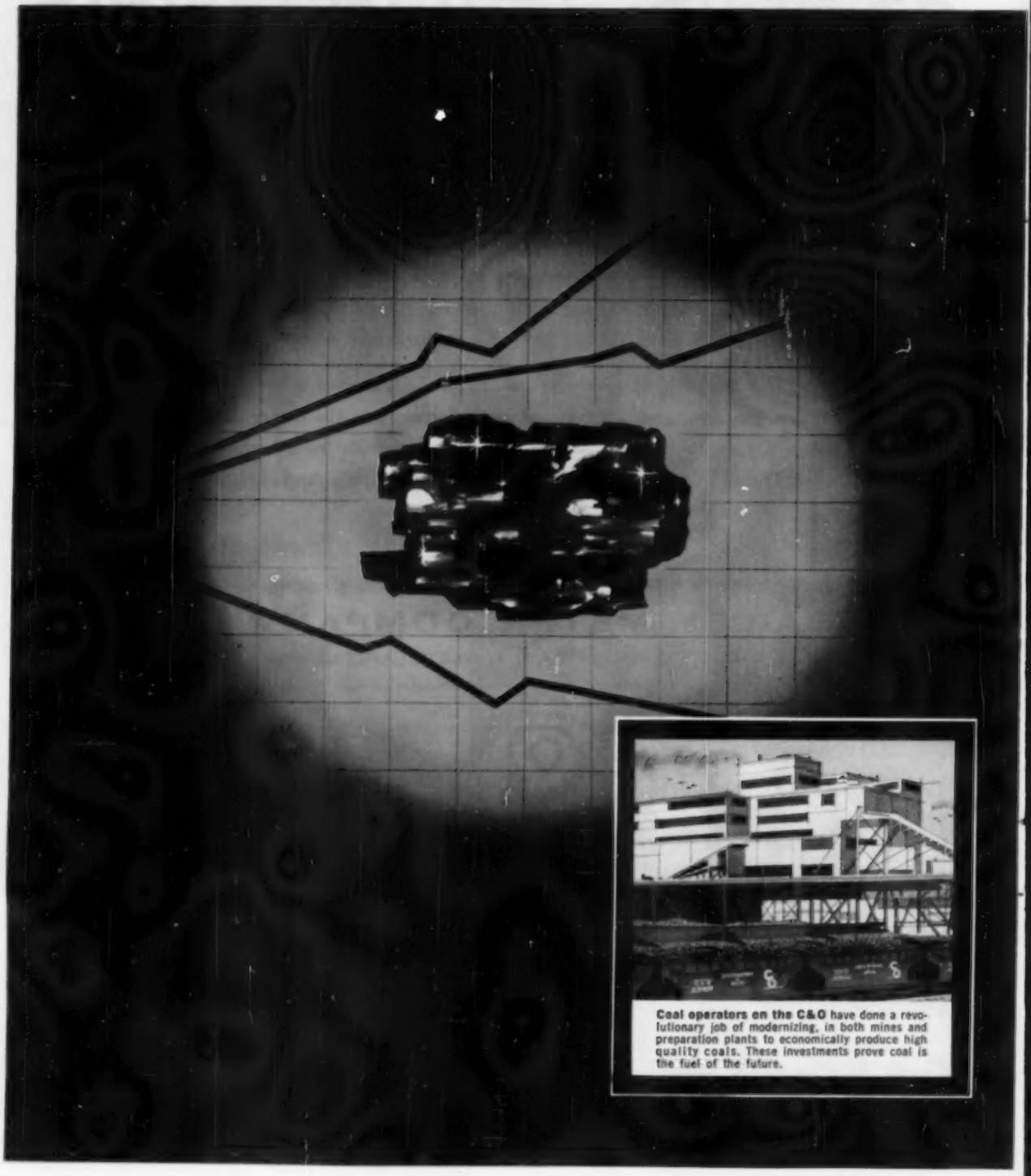


CLIFTY CREEK (Indiana-Kentucky Electric Corp.)—top five, 1955-1958, averaging 9155 Btu/kwhr.



PHILIP SPORN (Appalachian Power Co.—Ohio Power Co.) —top fifteen, 1954-1958, averaging 9378 Btu/kwhr.

REDISCOV



Coal operators on the C&O have done a revolutionary job of modernizing, in both mines and preparation plants to economically produce high quality coals. These investments prove coal is the fuel of the future.

ER COAL !

COAL IS ECONOMY– proved in countless studies with competitive fuels

As forward-looking fuel users continue to *rediscover coal*, a growing file of case histories proves out the economy, versatility and convenience of coal utilized with modern combustion equipment. Here are a few graphic examples.

A sprawling university undergoes plant modernization, upgrades heating efficiency 75%. Coal saves a military institute $15,041 yearly over competitive fuel. A machine shop saves $7,787. Coal conversion gives a small tool plant completely automatic operation at lowest cost. An automotive assembly plant reports not only fuel economy but low maintenance, high efficiency and cleanliness as well, from its new coal operated steam plant.

The point is this. Modern advances in coal preparation, handling and combustion equipment have vastly improved the advantages of this biggest bargain in fuel. Today it is mined and transported more economically than ever. And coal is the one fuel certain for *centuries, not decades.*

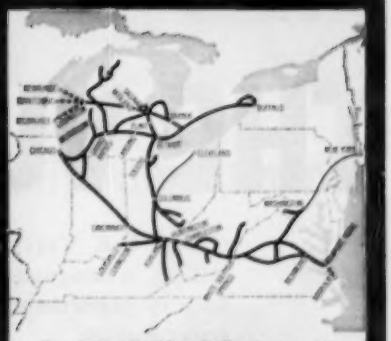
Chesapeake and Ohio Railway

Terminal Tower • Cleveland 1, Ohio

Outstandability in Transportation

A modern boiler room in pastel colors has a clean, almost clinical appearance. Automatic sealed handling of coal and ash eliminates dust. Advance-design combustion equipment gets top BTU's from low cost coal.

C&O Fuel Service Engineers provide free consultation to C&O patrons on combustion, application, equipment, or plant arrangement problems. Write to R. C. Riedinger, General Coal Traffic Manager, above address.



The 5100-mile Chessie Route directly serves over 300 mines in America's richest bituminous coal reservoir with the finest fleet of 68,000 coal cars. Specify C&O routing for dependable, efficient delivery.

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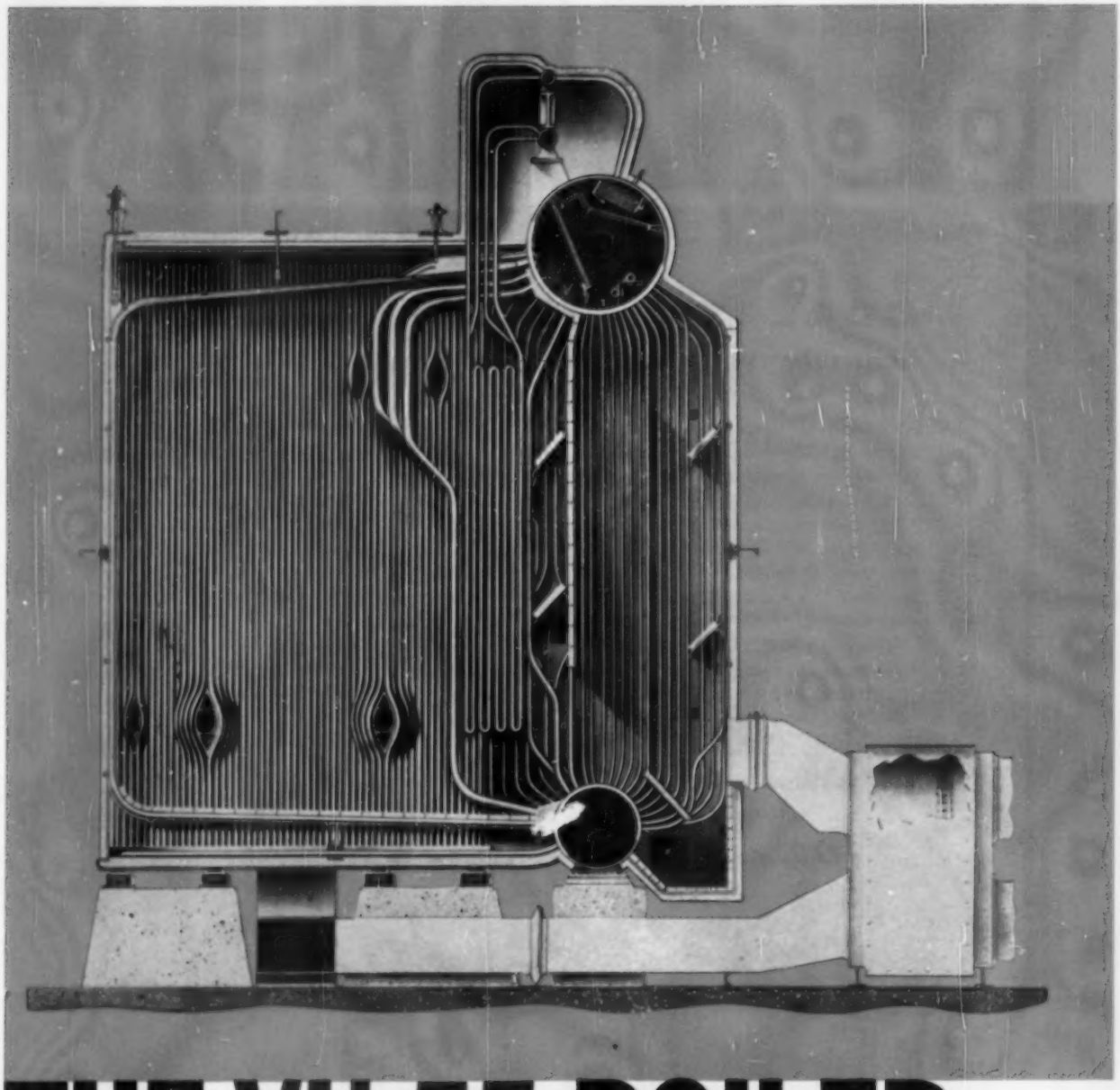


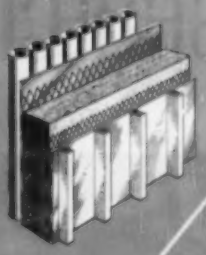
THE VU-55 BOILER...

The C-E Vertical-Unit Boiler, Type VU-55, is designed to bring central station type of performance to the "standardized" boiler market.

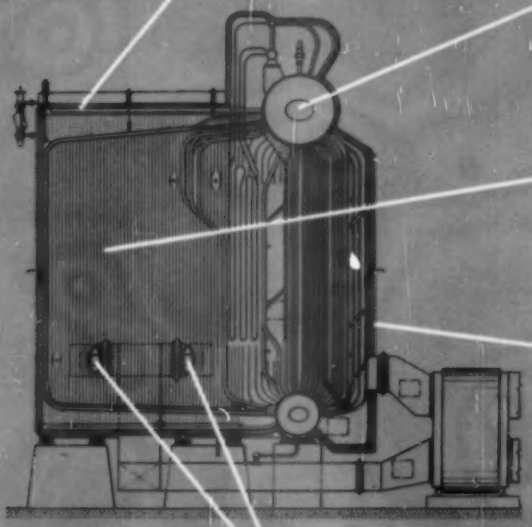
It combines a number of time-tested and service-proved features such as Tangential Burners, pressure-tight casing and tangent furnace tubes. This bottom-supported unit requires no outside supporting steel, is economical of space and has an uncluttered, streamlined appearance.

The VU-55 is available from 70,000 to 150,000 lb of steam per hour. It is designed for three pressure ranges (250, 500 and 750 psi) and can be equipped with a superheater to provide temperatures up to 800 F.

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS;



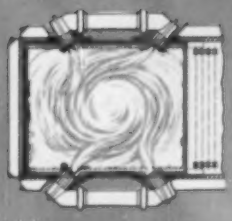
PRESSURE-TIGHT, SKIN CASING. A service-proved method of casing construction for pressure-fired boilers in the size class of the VU-55, this casing is designed to assure life-time tightness with minimum heat loss. Pressure firing permits the elimination of an induced draft fan with its attendant operating and maintenance costs. Wall construction consists of tangent tubes backed up successively with welded steel panels, 4 inches of high quality insulating material and an outer steel casing formed as shown to provide adequately for expansion and to give a neat, finished appearance.



HIGH STEAM QUALITY. The VU-55 has generous water capacity and steam reservoir space. Its drum internals are exceptionally effective in producing high quality steam at all ratings.

TANGENT FURNACE TUBES. The VU-55's furnace tube arrangement provides complete heat-absorbing, water-cooled protection on all furnace walls. Furnace maintenance is minimized, refractory expense is eliminated.

STREAMLINED EXTERIOR. The over-all appearance of the VU-55 reflects the efforts of its designers to achieve a completely unobstructed casing, while retaining adequate access wherever required and every facility for convenient operation. There are no outside downcomer tubes, and the ducts from air heater to burners are beneath the furnace floor.



TANGENTIAL FIRING. More than 20 years of application experience have established the exceptional advantages of tangential firing. About 90 percent of Combustion's large utility installations use this advanced method of firing. Flame streams from the four burners impinge upon one another at high velocity, as shown, creating a turbulence unattainable by any other method of firing. The result is rapid and complete combustion. As the gases spiral upward, they sweep all furnace heating surfaces, assuring a high rate of heat absorption.

a "standardized" boiler with "custom-built" performance

The unit is symmetrical in design, performs efficiently over a wide range of output, and is exceptionally easy to operate and maintain.

When you are considering additional steam capacity in the quantity range mentioned above don't fail to investigate the advantages of the VU-55.

COMBUSTION ENGINEERING

C-E

C-261

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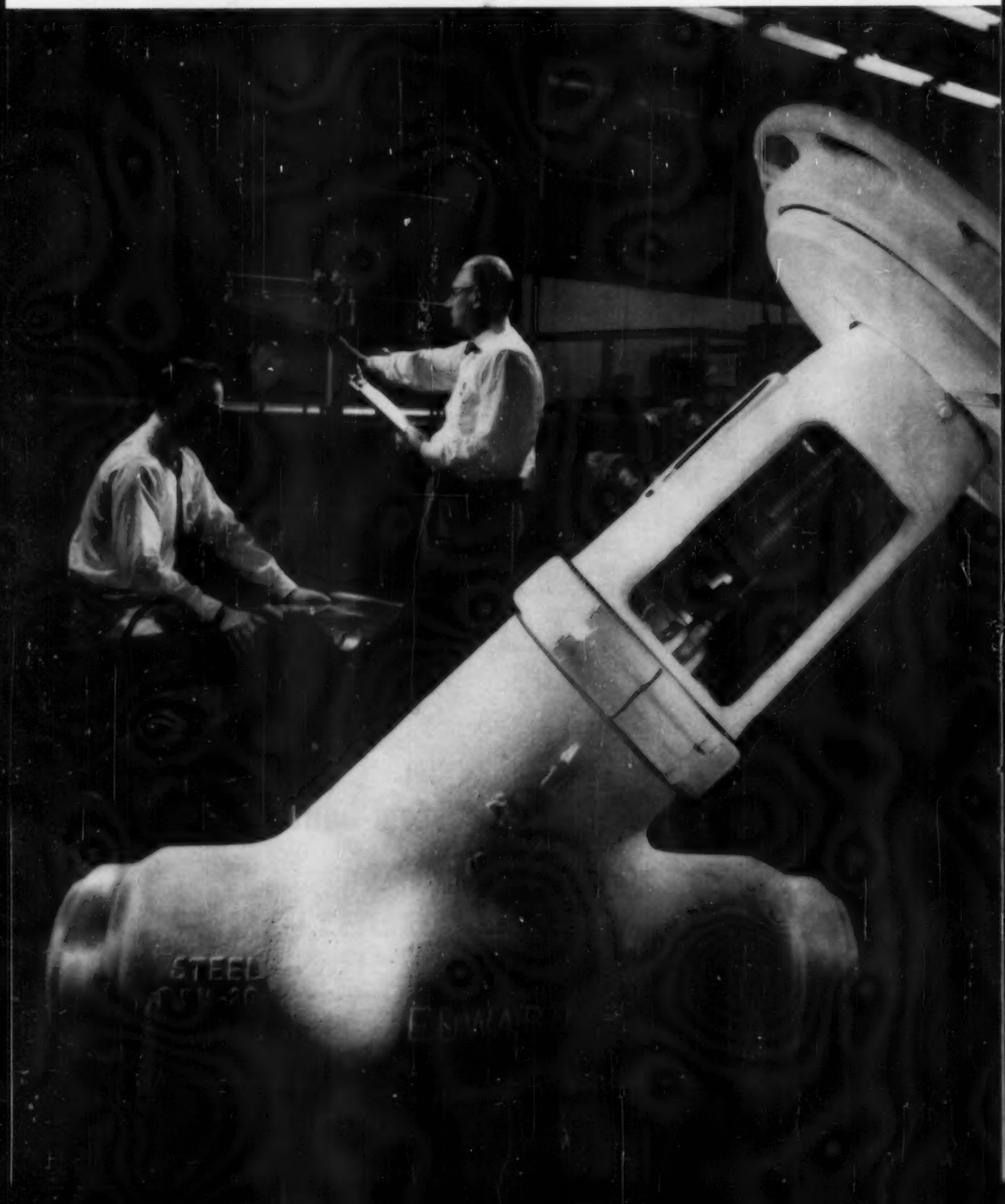
Canada: Combustion Engineering-Superheater Ltd.

PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

How Edward Valve Research



Reduced Pressure Drop 70%

Power industry advances in unit size created a need for large, high pressure steel valves (ten inch size and larger, 1500 lb class and higher) with three basic qualities: 1. Permanent tight seating; 2. Capacity to handle high flow rates being encountered in new, high pressure plants; 3. Reduced downtime through simplified maintenance. Edward researchers developed the Flite-Flow* design to satisfy that need. This is their story.

In 1951 Edward had already developed large cast steel globe valves with excellent dependability and repairability. Long experience in building inclined stem Y-type valves in small sizes indicated that this configuration offered a more efficient flow path. Edward research engineers set out to learn whether sufficiently strong pressure containing structures might be built in the Y-type design in larger sizes. They also sought to find out if pressure drop could be reduced sufficiently to make such a valve practical for high pressure power plant services.

The project consisted of three steps:

1. INTERNAL CONTOUR DESIGN—Flow tests were conducted with a series of plastic models. Early in the testing program it was observed that flow capacity was not always directly related to the size of the opening. Reduction of turbulence proved to be even more important. This eventually led to subtle internal contour changes to pre-shape the flow before passing through the valve seat. More material was added to certain internal areas to gain additional structural strength.

2. DISK GUIDING TESTS—To compensate for the angular position of the stem-disk assembly tests were conducted to determine whether conventional three-point guiding used in vertical stem Edward valves would be adequate for the inclined stem design. Experiments suggested that four equally spaced guiding surfaces would be superior. This is important in floating disk types such as check or stop-check valves where disk-piston assembly must seat automatically.

*T.M. Reg. U.S. Pat. Off.

3. STRUCTURAL STRENGTH—The usual weakness of a Y-type pressure containing vessel received much attention. Optimum valve contour as determined by flow testing permitted use of a structural member in the flow passage at the downstream side of the seat port. This structural member provides strength exactly where needed without significant increase in pressure drop. Introduction of this segment to the valve body casting without sacrifice in pressure drop was a significant achievement.

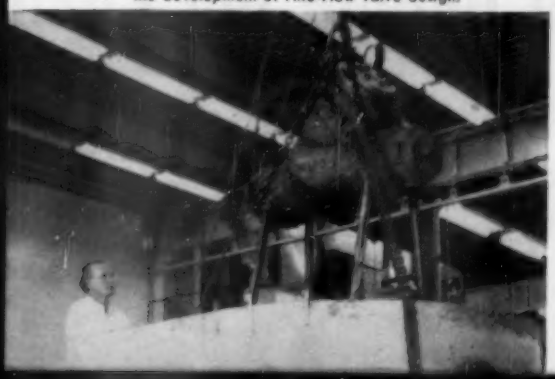
RESULTS: This program covered a period of six years. Tests of the completed design were most gratifying. Structural stability, a major problem, was excellent. Strain gage and brittle lacquer tests of finished valve bodies showed stresses well within acceptable limits. Pressure drop reduction amounted to as much as 70 per cent from best previous globe valve experience. Extended tests of finished product at pressures and temperatures above rating showed no operating weaknesses. The Flite-Flow is truly a dependable, repairable, low pressure drop valve.

Edward builds a complete line of forged and cast steel valves from ¼" to 24" for industrial, marine, petroleum and technological services. For more detailed information, contact your Edward Representative, or write Edward Valves, Inc., 1206 West 145th Street, East Chicago, Indiana. Subsidiary of Rockwell Manufacturing Company. Represented in Canada by Lytle Engineering Specialties, Ltd., 438 St. Peter Street, Montreal.

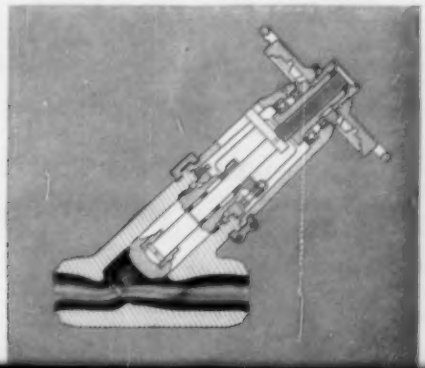
EDWARD STEEL VALVES
another fine product by
ROCKWELL

◀ W. G. Lunt, research engineer, and E. B. Pool, chief research engineer, study flow phenomena in plastic half-model of tentative Flite-Flow design.

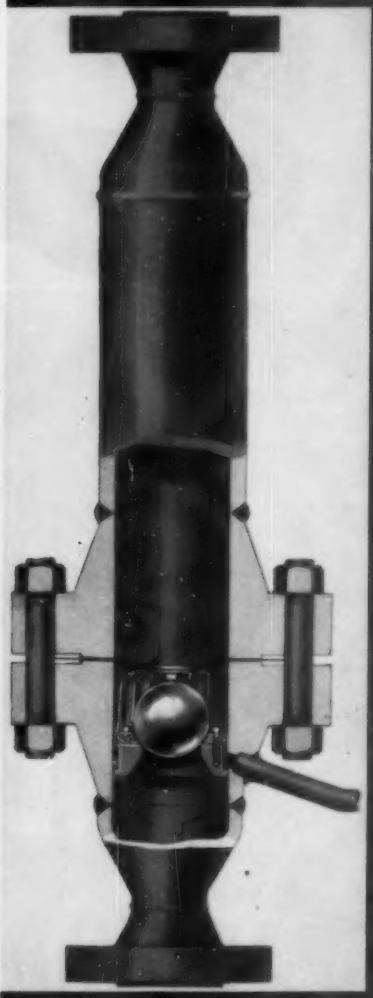
▼ Edward research team lowers experimental valve into test furnace where it is subjected to prolonged extremes of heat and pressure. This was one of the final steps in the development of Flite-Flow valve design.



Cutaway view of Flite-Flow valve showing how inclined stem Y-type valve configuration has been adapted to larger size units for power plant services. This internal contour design enabled Edward research engineers to substantially reduce pressure drop.



H. J. Heinz relies on Copes-Vulcan reducing and desuperheating station to handle big changes in steam demand



(Far left) **Chart on left side of panel** shows wide load changes. Chart on right indicates exacting pressure and temperature control. Station takes boiler steam at 600 psig and 750 degrees F. and delivers it to process at 110 psig and 360 degrees F.

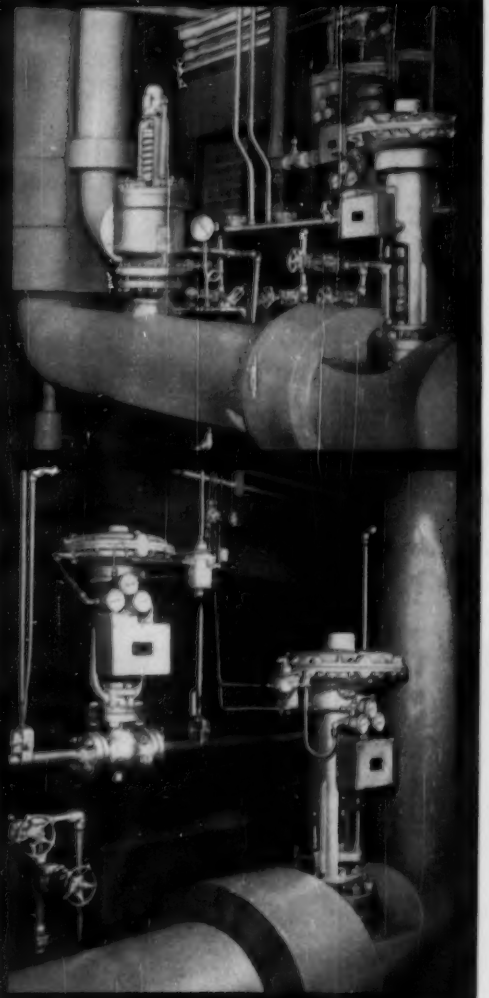
(Cutaway at left) **A weighted steel ball controls orifice opening,** speeds intimate mixing of cooling-water and steam. No atomizing steam, spray nozzle, or glands required. Write for Bulletin 1037.

(Upper right) **The 8-inch, 300-pound pressure desuperheater** is installed in the insulated vertical run of steam piping at the far left. The cooling-water control valve is behind the pressure reducing valve in the right foreground.

Fast acting valves assure rigid control
Cooling water flow for the desuperheater is controlled by a 1-inch, 300-pound standard Type CV-D diaphragm valve (left) actuated by a temperature controller.

The 600-pound standard Type CV-D reducing valve (right) has a 4-inch inlet and 8-inch outlet to take care of steam expansion at reduced pressure. Its positioner assures accurate control modulation.

Copes-Vulcan diaphragm type valves can be direct or reverse acting. Piston types are also available for high duty service, assure maximum power with precise positioning. Write for Bulletin 1027.



Working with flow rates that vary from 0 to 70,000 pounds per hour, this Copes-Vulcan reducing and desuperheating station holds process steam to plus-or-minus 4 psig and plus-or-minus 5 degrees F. with only 16 degrees F. superheat. Wide fluctuations in steam requirements often occur extremely rapidly at the H. J. Heinz plant in Pittsburgh. On a typical day, the load increased from 0 to 47,000 pounds per hour within 15 minutes, then dropped back to 5,000 pounds per hour in even less time.

Made up of a Copes-Vulcan Variable-Orifice desuperheater and diaphragm operated Type CV-D valve, this type of station represents a new approach in process steam control. Since its installation over a year ago, the station has maintained an outstanding record for continuous accuracy.

Whatever your operating conditions, Copes-Vulcan has the desuperheating station for controlling your reduced steam temperatures. Besides the Variable-Orifice type, the line includes a Steam-Assist type and a Carburetor type. Write for details.
Copes-Vulcan Division, Erie 4, Pennsylvania.

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COOPER-BESSEMER
DMR-3 THREE-STAGE
AIR COMPRESSOR
FOR
SOOT-BLOWING
200 TO 400 HP

S. D. Greiner, *Air Compressor Sales Engineer,*
The Cooper-Bessemer Corporation, explains...

How Cooper-Bessemer's new, compact Air Compressors cut soot-blowing costs

Compressed air provides important cost savings for soot-blowing in coal or oil-fired power plants. Glance at the list of advantages shown at the right.

Now, Cooper-Bessemer introduces further economies in favor of AIR as the soot-blowing medium. The new line of DMR Air Compressors provides a new standard of *installation* economy. So highly *compact*, the DMR units can be installed in small space, conserving on floor area and making it possible to locate them near the boiler for greatest efficiency.

The new DMR units come completely equipped with integral motor-drive and intercooler... ready for operation. Control can also be integrally mounted as shown. They are available for three-stage applications in the range of 687 to 1029 cfm free air and discharge pressures of 350 and 500 psi.

Complete details on this new line of Cooper-Bessemer air compressors are given in Bulletin No. 94. Call the nearby Cooper-Bessemer office or air compressor agent for your free copy.

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5. Much less maintenance of blower equipment due to erosion, corrosion, packing wear.
6. Improved housekeeping... no steam or condensate leakage.
7. Greater over-all economy of blowing medium on evaluated basis.
8. Eliminates condensate makeup required when blowing with steam.

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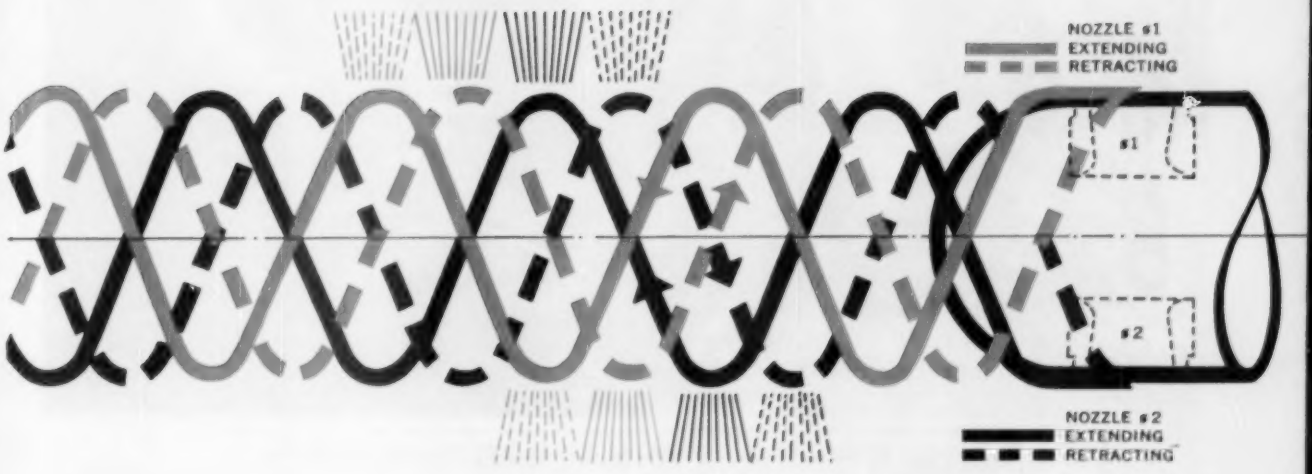
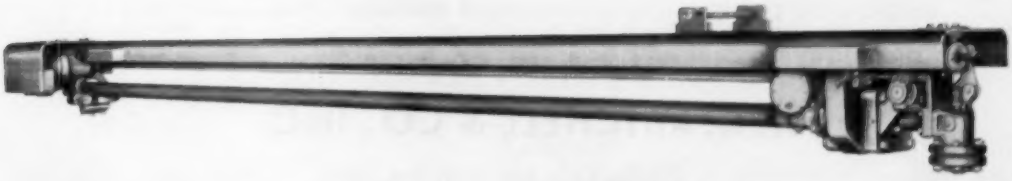
IK's are just part of the reason behind Diamond's established superiority in boiler cleaning systems. Add a complete line of cleaning equipment, an experienced, imaginative engineering staff and an unmatched service organization. No wonder thousands of utility and industrial power plants are equipped with Diamond Cleaning Systems — engineered and designed to provide you with more economical power.





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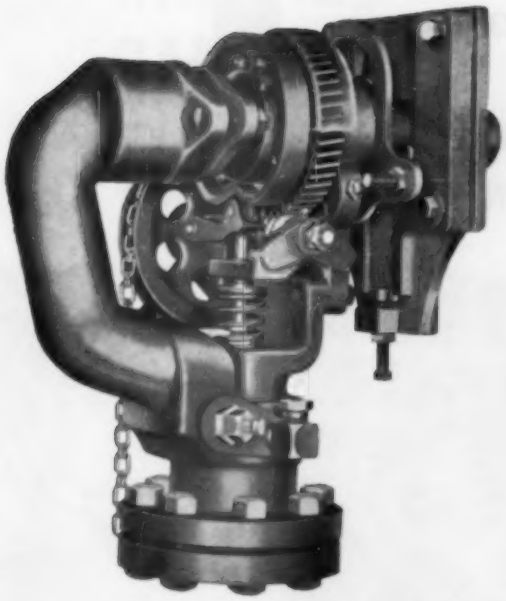

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- minimum steam consumption
- superior high temperature resistance

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ADVANTAGES OF THE BAYER BALANCED VALVED SOOT BLOWER

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- complete vacuum breaker protection
- precision swivel tube alignment lessens stuffing box packing needs
- load carried on ring type thrust bearings

For further information contact the Bayer representative nearest you. He is an experienced engineer, qualified to service Bayer Soot Blowers.

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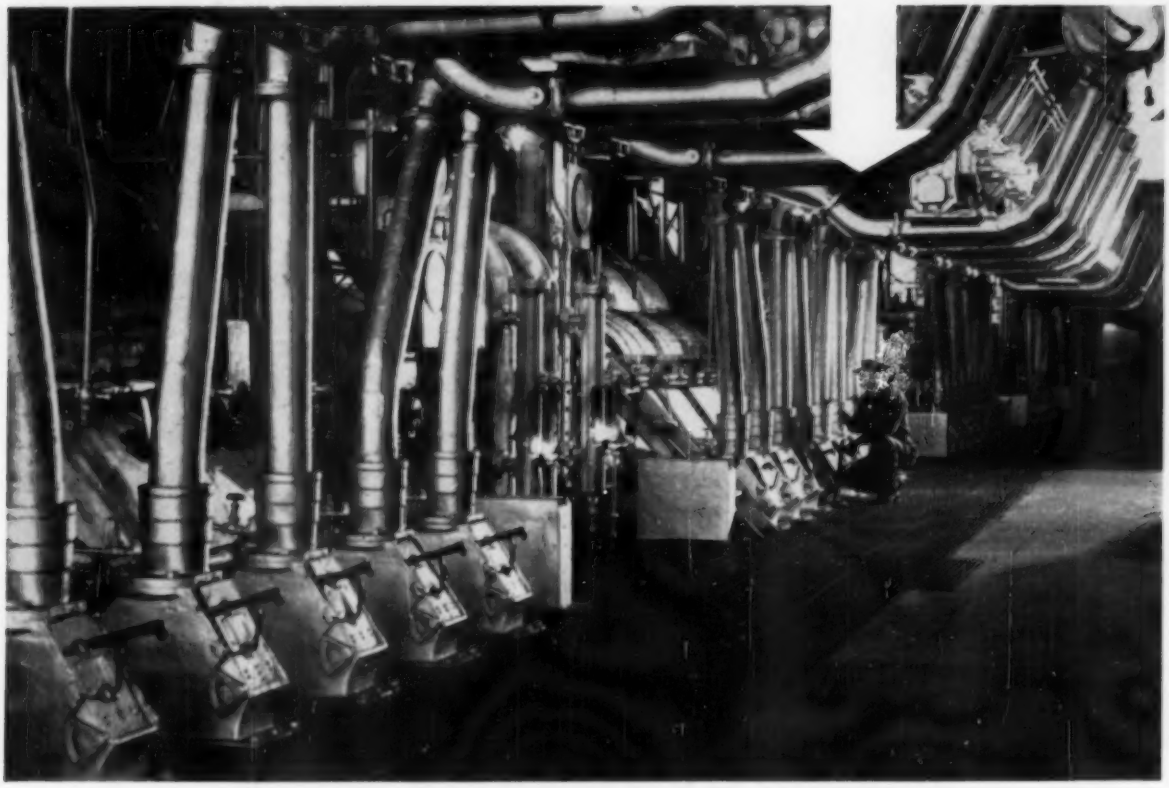

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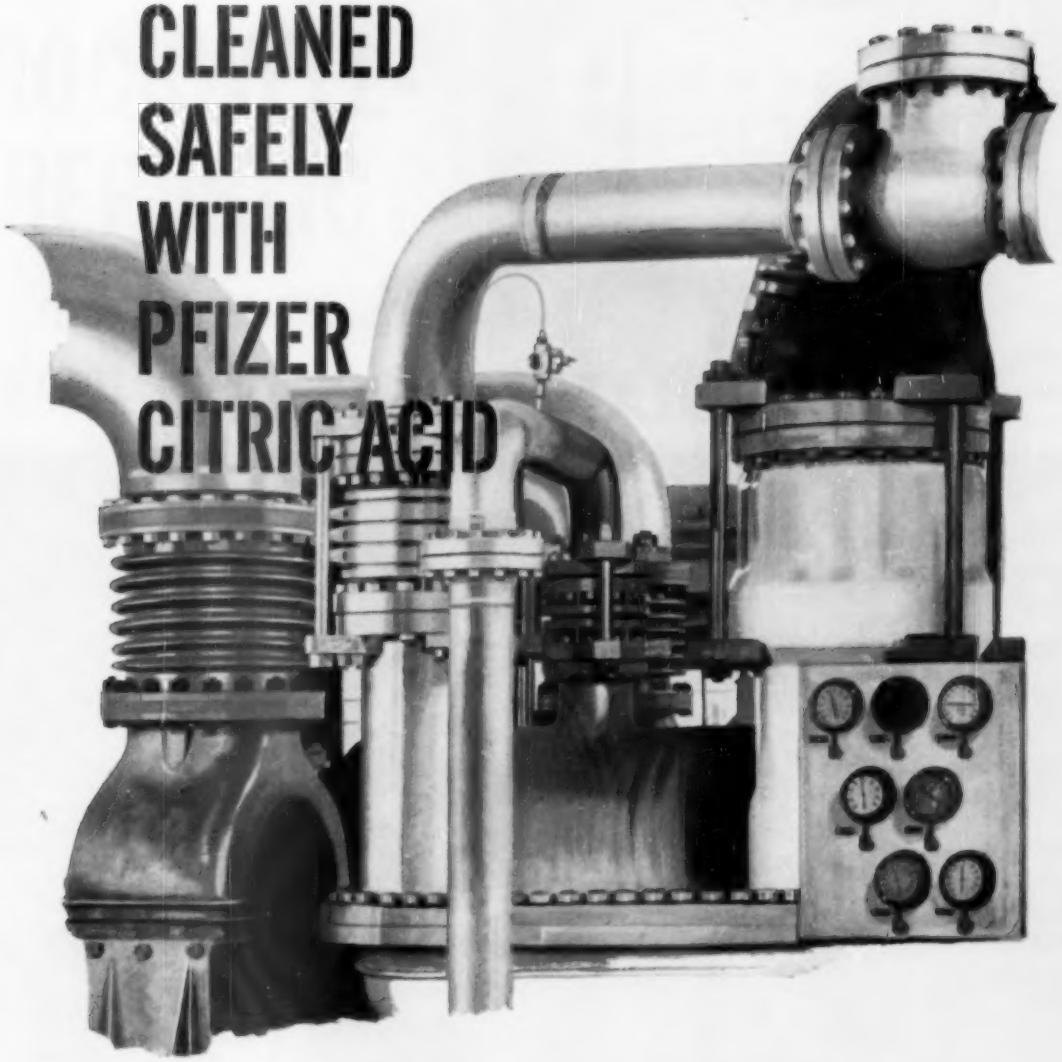

STAINLESS STEEL BOILERS, HEAT EXCHANGERS, ATOMIC INSTALLATIONS, CHEMICAL PROCESSING EQUIPMENT CLEANED SAFELY, EFFICIENTLY WITH PFIZER CITRIC ACID

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INDIAN POINT

Indian Point Station as it looked in April this year, showing some of the piping to be installed by Kellogg's Power Piping Division

NUCLEAR POWER PIPING BY KELLOGG

Construction progress at Consolidated Edison Company's Indian Point Station demonstrates how Kellogg's broad erection experience can take tomorrow's newest and toughest power piping requirements in stride.

At this unique 275 Mw nuclear steam electric generating station, Kellogg has a contract to manufacture, deliver, and to erect all stainless and carbon steel nuclear piping for the inside of the reactor sphere, and all power piping for the conventional portion of this plant. Kellogg also stress-analyzed the major portion of this piping. Much of the stainless piping will be manufactured in Kellogg's Williamsport plant.

The particularly rigid specifications of high quality and close tolerances required the assignment of a special engineering staff to the site. This staff plans, coordinates and supervises each step of Kellogg's erection assignment. One important phase entails over 2200 critical welds, most utilizing Kellogg's K-Weld technique. Another is the radiographic inspection of each weld, which Kellogg is undertaking with its own equipment and personnel.

Kellogg welcomes inquiries for its stress analysis, metallurgical, engineering, manufacturing and erection services.

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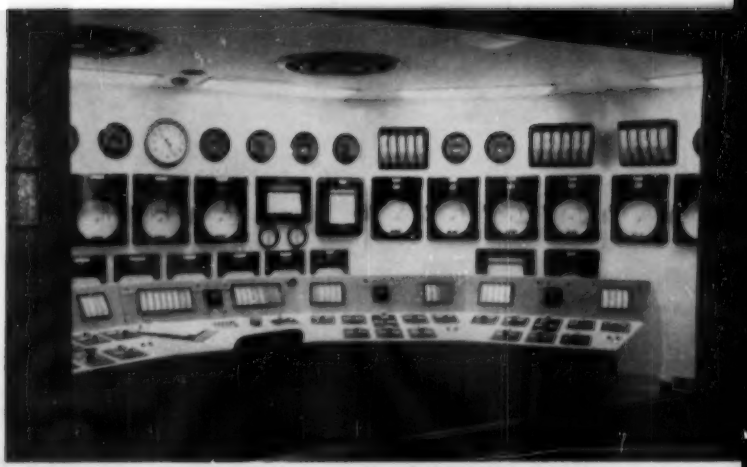
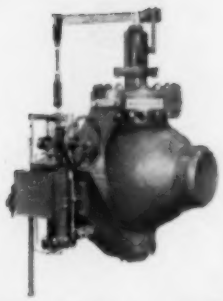
ROCKWELL-REPUBLIC

INSTRUMENTS, CONTROLS, AND VALVES



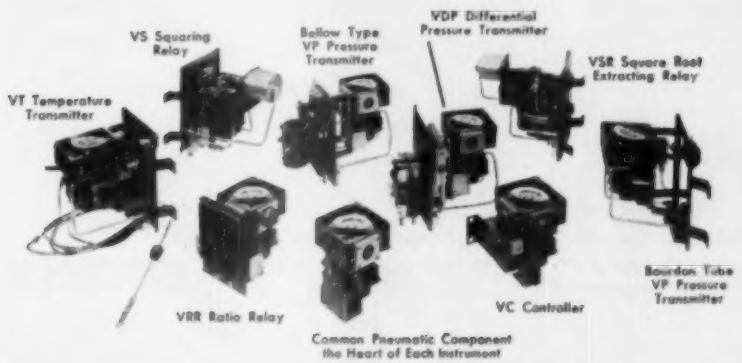
Rockwell-Republic Control Systems. Republic engineers and furnishes equipment for both electronic and pneumatic control systems, for use on large central stations, package boilers, process industries, and steel mills. Republic has installed more than 125 electronic control systems since the first one in 1949. They total more than 400 unit-years of operation. These central systems automatically control steam pressure, combustion, furnace pressure, excess pressure, boiler level, and other variables.



Steam Dump Valve. Series 700 double-seat valve (600 psi) with Series 73 positioner. Valve shown used in nuclear power plant to dump steam to condenser when steam must by-pass turbine.

Quick-Change Trim V-10 Valve. For severe services up to 4500 psi, newly improved regulating valve features quick-change trim that allows dismantling and reassembly within minutes without removing valve from line.

Improved Final Drive Unit. Operates valves, dampers, inlet vanes, etc., in response to either pneumatic or electronic signals from remote control station. Can also be operated manually. Power is pneumatic.


VS Squaring Relay
Bellow Type VP Pressure Transmitter
VDF Differential Pressure Transmitter
VSR Square Root Extracting Relay
VT Temperature Transmitter
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VC Controller
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M/A Control Stations. Republic offers a complete line of compact, panel mounted control stations for use with Null-Balance-Vector instrument control systems. These control stations are made in several types to accommodate a wide variety of pneumatic control applications.

In addition to the above items, a complete line of Rockwell-Republic instruments and controls including Desuperheaters, Electric Transmitters, Flow Meters, CO_2 meters, valves, and others is available. Write to Republic Flow Meters Company, Subsidiary of Rockwell Manufacturing Company, 2240 Diversey Parkway, Chicago, Illinois.

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CLASSIFIERS Capacity to keep up with any mill . . . low power consumption, no moving parts.

Combustion

EDITORIAL

Too Much Security?

The air was full of political noises last month as both major parties designated their presidential hopefuls. Amid all the viewing-with-alarm and proclaiming without-fear-of-contradiction one significant fact emerged. Both party platforms will be characterized by more security for everyone. Uncle Sam will play Big Brother so we faceless ones can have a bigger chicken in every pot. The only hope for the taxpayer lies in the political adage that platforms are to run on, not necessarily to stand on.

We have noticed that this canker of creeping security has a serious effect on engineering organizations. New ideas are stifled because they're different. Their authors choke them back for fear of failing—management rejects them for the same reason. The philosophy seems to be "You can't make a mistake if you don't make a decision."

The marshy turf of this security engendered and endowed morass of mediocrity can never be a spring board to progress. Overemphasis on fringe benefits inhibits progressive thinking and causes engineering projects to topple from the weight of checks and balances required to prevent anyone from venturing beyond the frontiers of "what we did last year."

Personal security, now and always, lies only in the head and the heart—knowledge and courage of conviction—and not even Big Brother can guarantee material security beyond the next heartbeat.

Young engineers with enthusiasm and ideas might profitably lay aside for a moment their pension plans, major medical benefits, paid vacations and holidays and look about for the companies who are moving ahead—who are risking real capital on the wheel of the future.

Older engineers who find themselves deep in a security-plowed rut may ponder the difference between a rut and a grave. In a rut one can still see the sky and climb toward it.

Direct Conversion of Energy to Electricity

Fig. 1—Experimental thermionic tube is demonstrated by Dr. W. J. Coltman, Westinghouse scientist. Inside the tube glowing wire emits electrons causing current flow in ionized cesium gas

By R. C. ULMER and J. D. SENSENBAUGH

Combustion Engineering, Inc.

OUR LIFE revolves around electricity and its many uses. We have come to take it for granted. Yet many recent press releases and technical magazines have carried notices of advances made in producing electricity. Most cases have dealt with direct conversion of energy to electricity. Fig. 1. What are such processes? Are they new? Is one of the methods likely to replace present ones for generating electricity? Will the cost of electricity be less? These and other questions will be answered and as a sort of preview of what is to come, may we say that the answers will depend pretty much on whether one is considering electricity from the standpoint of the few watts for a satellite in space or the millions of watts for even a small city.

First let us be sure we all understand what electricity is and the common means by which it is produced. We now define electricity or electric current by referring to the atomic theory. More specifically, all matter is made up of tiny particles or atoms. Atoms contain electrons which are negatively charged, protons which are positively charged and neutrons which have no charge. The electrons are in the outer part of the atom and are free to move from one atom to another. When these electrons move in one direction an electric current results. A good conductor of electricity is a material in which the electrons readily move from atom to atom. An insulator or poor conductor on the other hand is a material in which the electrons are more firmly bound or attached to the atom and, therefore, do not move freely. Although the electrons pass from one atom to another, the conductor is not changed noticeably by the process. This is due chiefly to the fact that many electrons are involved with even a small amount of electricity and the "average" condition of the material does not change. For example, a 60 watt lamp requires the "passing" of 3,000,000,000,000,000,000 electrons per second. Although this is a tremendously large number it is small in comparison to the number of electrons in an inch of even the finest wire.

Common sources of electricity are batteries and power plants. By far the most electricity originates from the latter. Energy is converted into electricity and the chief energy source is heat from fuel. But the heat is not directly converted into electricity, it first is used to generate steam which turns the turbine which rotates an armature through an electrical field. Electricity is caused to flow in the circuit of the armature and through transmission lines the electricity is conducted to houses, factories, etc.

Now generation of electricity by this process is very wasteful. Actually only about 40 per cent of the heat in the fuel is converted into electricity, the remainder being lost generally in the cooling or condensing process. Owing to the low thermal efficiency, Fig. 2, there has been a lot of effort and thought given to other means for generating electricity. By other means is meant a process not involving the intermediate step of converting heat to some form of energy which in turn operates a generator. In this respect, nuclear energy is not a different process as the heat required is merely supplied by nuclear means, the rest of the cycle remains the same. Consequently, the efficiency of this method is the same as for presently used steam electric generation, namely 40 per cent. There are some processes which are more efficient, as high as 80 per cent. These generally involve direct conversion of the form of energy concerned to electricity. This is intriguing to say the least, for we have pointed out that matter is elec-

tronic in nature. "Line up" the electrons so they will pass from one atom to another and an electric current will flow? Let us now consider some of these possibilities, their applications and limitations.

Unconventional Methods of Power Generation

In recent months, the technical journals have contained numerous items pertaining to novel methods of power generation. These items range from research reports and review articles covering certain methods to announcements of devices developed by various organizations. This report attempts to classify unconventional methods of power generation, indicating the field of application and current state of development of each.

The use of nuclear energy in nuclear power plants will be considered a conventional method of power generation in which the nuclear reactor takes the place of the boiler in supplying heat to produce steam and operate a conventional generator. However, nuclear energy converters involving direct conversion of heat to electricity will be included.

Methods for Special Uses

The methods included in this section have definite fields of application, but do not appear promising for large scale use because of low power outputs and/or unfavorable economics.

Piezoelectric Generation

Certain crystals, Rochelle salt for example, exhibit a phenomenon known as the piezoelectric effect. When these crystals are subjected to compression or tension, their opposite faces acquire opposite electrical charges. The polarity is reversed when the stress is reversed. If the crystals are vibrated at 10,000 to 100,000 cycles per second, as much as 10 w/sq cm may be generated at efficiencies as high as 90 per cent. These crystals have been used in such applications as microphones, phonograph pickups and vibration meters. It is possible that materials may be found that give a greater output, but it is not likely that this method will be developed to the point of supplying large amounts of power.

Electric Generators

Devices in which an electrostatic charge is produced and transferred to a charged collector date back to the early days of electrical experimentation. In modern times, the Van de Graaff generator has been used in nuclear studies. This type of generator can produce a voltage as high as 10,000,000 v, but the current is only of the order of microamps, so that the power output is small. The efficiency is low, and the specific weight per unit of output is large. Furthermore, Van de Graaff generators are expensive. These disadvantages work against the use of electrostatic generators except for scientific purposes.

Solar Energy Converters (1–3)*

The utilization of solar energy has presented an intriguing challenge for many years, but formidable obstacles stand in the way of its accomplishment. At best the energy is available only part of the day, and under unfavorable weather conditions this availability is further limited. Furthermore, the density of solar energy received at the earth's surface is rather low, amounting to about 125 w per sq ft. This means that a large collecting surface is required. For example, it has been calculated that a 1000 kw solar power station would require approximately 14 acres of energy-receiving surface.

Solid State Devices

Solar radiation in the near ultraviolet through the

* Numbers in parentheses refer to similarly numbered entries in the Bibliography at the end of the article.

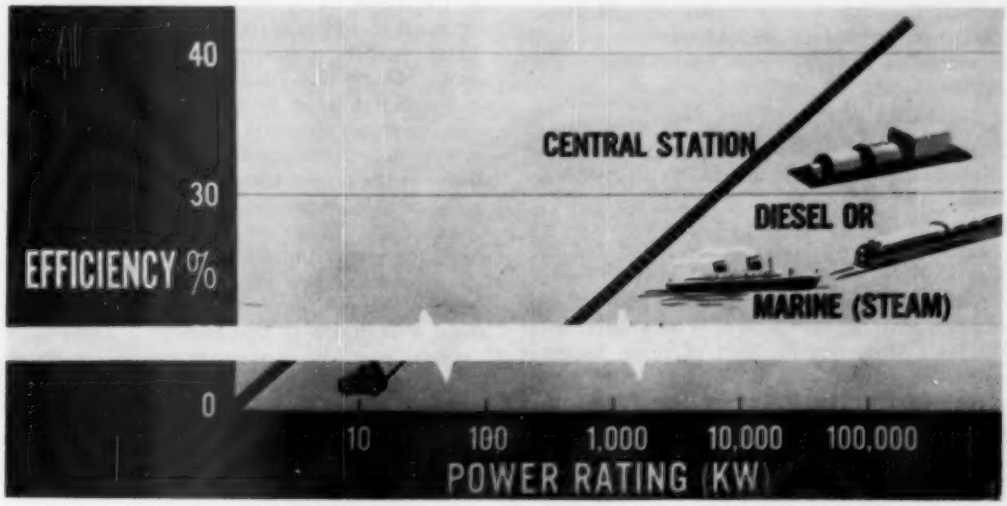

Fig. 2—Efficiency of conventional heat engines as a function of their power output

near infrared region is the only band which can be utilized at present. The use of cosmic rays or solar X-rays is not practical, since the energy flux is very low. In the future, it may be possible to utilize the very long wave length infrared, which consists of absorbed solar energy reradiated from the earth in quantities up to 20 per cent of the original solar radiation. At present, cells absorbing in this region of the spectrum have both low output voltage and low output current and hence low power output.

Theoretically, solar energy could be converted to electrical energy by using thermoelectric, thermionic, solar regenerative fuel cell, or photovoltaic devices. Only the latter method has been put into practice, using the photovoltaic converter with the silicon junction cell (developed by the Bell Telephone Laboratories) as the basic element. These cells are presently mass produced with a conversion efficiency of 10 per cent and many single elements show efficiencies of 12 per cent. The theoretical maximum efficiency for the current type of cell and using known semiconductor materials is between 20 and 27 per cent depending on the particular semiconductor used. Silicon cells should have a maximum efficiency of about 19 per cent but factors such as reflection losses reduce this to the 12 per cent maximum realized in practice.

Semiconductor devices have several advantages as solar energy converters. They are mechanically rugged, chemically stable, and have no moving parts.

Photochemical Conversion

Rather than converting the thermal energy into electricity, it might be possible to convert solar energy into chemical energy by means of photochemical processes. Suitable cells would then be employed to obtain electricity from the chemical products.

Certain fluorescing dyes produce a potential of the order of 100 millivolts when irradiated by visible light. A photochemical oxidation-reduction reaction is probably involved.

Another system that has been proposed involves the photochemical decomposition of water in the presence of ceric and cerous ions. The hydrogen and oxygen formed would be used in a fuel cell to produce electricity.

Although considerable research has been carried out on photochemical conversion processes, the efficiencies are low, and results to date are not too promising.

Energy Storage

Due to the intermittent nature of the solar energy supply, large scale application of solar energy conversions cannot be made unless suitable means of energy storage are available.

Workers at the Bell Telephone Laboratories have examined possible storage methods and concluded that electrochemical storage is presently the most attractive method from a technical standpoint. Lead-acid or nickel-cadmium batteries are technically feasible for solar energy storage. However, the cost of these batteries would have to be reduced by a factor of 2 to 10 to permit economic feasibility, and it does not seem likely that such cost reductions can be made.

Outlook For Use of Solar Energy

Since the outlook for economical energy storage appears bleak, the immediate outlook for solar energy utilization appears to be confined to special applications where little storage is required or where cost is a secondary consideration.

An example of an application that could operate on an intermittent basis might be the generation of power in desert areas to pump water to storage. Cost may be considered of secondary importance in certain military applications, such as unmanned weather stations or for radio transmission from space satellites.

For the latter purpose, solar power systems offer performance competitive with nuclear energy converters. When a solar power system employing silicon cells is used in a space satellite, operating conditions prevent the attainment of maximum efficiency so that the the overall efficiency of such a system without storage devices might be about 5 per cent. However, the life of such a system in this service is expected to be several years. If the life were only one year, the power to weight ratio would be 2600 to 3100 w-hr/lb, which is comparable to the present ratings of nuclear thermoelectric devices, such as the SNAP-III discussed below.

Nuclear Energy Converters (4–8)

Thermal energy from a nuclear reactor can be converted directly to electricity by thermionic devices. This is the method used in the Los Alamos plasma thermocouple discussed in a later section of this report. Heat from radioactive decay can also be converted to electricity by thermoelectric means. This is method used in the SNAP-III generator, which belongs in this section on methods suitable for special applications.

SNAP-III

The SNAP (Systems for Nuclear Auxiliary Power) generator, developed by the Martin Company under an AEC contract, has 27 pairs of thermoelectric elements arranged like spokes around a capsule containing radioactive material. The demonstration model exhibited earlier this year was fueled with 1760 curies of Po^{210}, but a fully-fueled unit will contain 3000 curies of this isotope. Other isotopes can also be used. The size of the core containing the radioisotope was chosen to permit the use of Ce^{144}, which has a half-life of 290 days compared to 138 days for Po^{210}.

The converter elements were developed by the Minnesota Mining and Manufacturing Company, working as a subcontractor to the Martin Company. These semiconductor elements are made of lead telluride, suitably doped with controlled impurities to provide response in the proper temperature range.

The SNAP-III weighs 5 lb and is $4^3/_4$ in. in diam by $5^1/_2$ in. high. When initially fueled with 3000 curies of Po^{210}, the power output is 5.3 w, and the efficiency is 5.5 per cent; at half-life, the output is 2.5 w at an efficiency of 5.2 per cent. This generator will deliver 9000 useful w-hr during its first half-life. This compares with 250 w-hr from 5 lb. of ordinary dry cells or 400 w-hr from 5 lb of silver zinc batteries, the best available chemical battery. Unlike conventional batteries, the efficiency increases with decreasing temperature.

Probable Improvements

The longer half-life of Ce^{144} would nearly double the

useful output in w-hr/lb compared to Po^{210}. The cerium fuel should also be considerably cheaper than polonium. Exclusive of fuel cost, it is estimated that the SNAP units can be mass-produced for approximately $200.

Use of Sr^{90} with a half-life of 28 yr would increase the w-hr/lb considerably, but the heat source would have to be redesigned to accommodate the lower power density. Such redesign would increase extraneous heat loss and thus reduce overall efficiency. However, the AEC is planning a 100-w unit fueled with Sr^{90} that will operate for 10 yr without servicing or refueling.

It is expected that relatively simple design changes and certain changes in materials will permit reduction of the present weight to less than 3 lb with little change in power or efficiency.

Projected Uses

The SNAP-III is expected to find terrestrial uses in the operation of remote beacons, weather stations, and the like, as well as a power source for satellites and space vehicles, for example in their radio or television communications systems. It is not expected to become a source of large quantities of power.

Promising Methods for Large Scale Power Generation

Fuel Cells

Fuel cells appear to overlap the preceding and the present classification. Some types do show promise for large scale power generation, while other types fall in the special use category. However, we have chosen to discuss them all in one section.

A fuel cell may be defined as an electrochemical device in which a fuel is oxidized and a substantial portion of the heat of combustion is converted directly to electrical energy. Reduction occurs at the cathode, liberating electrons to the external circuit; the fuel is oxidized at the anode; and an electrolyte completes the internal circuit. For large scale application, it would be desirable to operate with pulverized coal as the fuel, but to date all cells that have been at all successful have operated on gaseous fuels. It is possible that coal gasification could be employed to provide fuel gas for fuel cell use.

The most important requirement to be met in a successful fuel cell is the reactivity requirement, that is, the desired reactions must occur at each electrode, and they must occur rapidly enough to give a satisfactory current density. This requirement has blocked the use of coal and makes it probable that only cells using gaseous fuels will succeed in the forseeable future.

The reactivity requirement can be met by utilizing the usual methods for increasing reaction rates, such a increasing the surface area, increasing the temperature and/or pressure, or activating the surface by suitable preparation or by incorporating catalysts. Another way of meeting the reactivity requirement is to react the fuel and oxygen with suitable chemical intermediates in regenerators external to the cell. These intermediates then provide the electrode reactions, and they are, of course, selected so that the electrode reactions are sufficently rapid.

Increasing the surface area is the most effective of these techniques. This is almost always done, even though other measures are also taken, and it usually is accomplished by using porous "gas diffusion" electrodes. High pressure and high temperature are often employed, but corrosion and leakage problems are increased. Surface activation is also often used, even though the activity decreases as the cell is used.

To be effective, gas diffusion electrodes must not permit gas leakage into the electrolyte. Nor can they allow the electrolyte to fill their pores, "drowning" them and making them inactive. This is a problem when hydrogen is used as fuel, as the water formed in the cell reaction will drown the electrode if it is allowed to become liquid.

Increasing the electrode reaction rate by using suitable intermediates promises to be the best means for obtaining high current density at low temperatures without drowning problems.

The Bacon Cell

The Bacon Hydrox fuel cell is the most highly developed cell. It will be described in some detail as an example, while other cells will be treated more briefly.

F. T. Bacon has been working in England on fuel cells for over 20 yr. Ten years of work at Cambridge University were sponsored by the Electrical Research Association and the Ministry of Power. Then in 1957 the National Research and Development Corporation placed a development contract with Marshall of Cambridge, an electronics firm.

The Hydrox unit consists of 40 cells, 10 in. in diam. The total output is $2^1/_2$ kw at 32 v or 5 kw at 24 v maximum load conditions. The unit itself is 30 by 15 by 12-in. but with gas supply tanks and control equipment it weighs about 700 lb and is big enough to fill a large truck.

Each of the individual cells contains two electrodes separated by an electrolyte. The electrodes are made of porous sintered nickel, with a thin layer having a smaller pore size on the liquid side. The oxygen electrode is treated with lithium and preoxidized to prevent corrosion. The electrolyte is concentrated KOH. Operating conditions are approximately 200 C and 400 psi. The electrolyte soaks into the sintered metal, and when the gas is admitted under pressure to the back of the electrode, the liquid is forced out of the larger pores only. The surface tension of the liquid prevents the gas from escaping through the smaller pores. Thus each electrode has a large surface (about 40 sq m) of wetted sintered metal in contact with the gas.

At the oxygen electrode, hydroxyl ions are formed, removing electrons and leaving the electrode positive. At the hydrogen electrode, hydroxyl ions combine with hydrogen to form water, giving up electrons in the process. Thus the hydrogen electrode becomes negatively charged with respect to the oxygen electrode, and a current flows through the external circuit. To remove the water formed, the hydrogen is circulated past the back of the hydrogen electrode, and the mixture of hydrogen and steam is cooled outside of the cell to condense the moisture.

Careful control of the hydrogen and oxygen is essential. The oxygen pressure is kept constant, and the hydrogen

pressures controlled with respect to the oxygen by a differential pressure system.

Efficiencies up to 80 per cent have been reported, (19) and Bacon cells have operated as long as 1500 hr using pure hydrogen as fuel. The life of the oxygen electrode appears to be the limiting factor with regard to prolonged operation of Hydrox cells.

These cells are able to take large overloads without damage, although the efficiency is reduced. They are silent and vibration-free in operation, have few moving parts, and the exhaust consists only of water. Despite these advantages, these cells are of interest only for specialized military and possibly civilian applications. They are not regarded as a possible major power source because the high fuel cost outweighs the advantages. For operation on 99.5 per cent hydrogen, a fuel cost of 14 mills/kwhr has been calculated. (23)

Present Status of Fuel Cells

The hydrogen-oxygen cell, as exemplified by the Bacon cell, is the most advanced type and has produced the highest power outputs and current densities obtained to date.

Since the Bacon cell has received considerable publicity, it may be helpful to untangle the complicated commercial arrangements for exploiting this cell in this country. For some time, the Universal Winding Company has had an exclusive American license for the use of the Bacon Hydrox fuel cell, and their Patterson-Moos Division has been engaged in further research and development activities.

Recently, (15) Universal Winding signed a licensing agreement with the National Research and Development Corporation of England covering other types of fuel cells, including the Carbox cell. The Carbox cell, developed by Dr. H. H. Chambers, burns carbonaceous fuels, such as H_2–CO mixtures or gaseous hydrocarbons.

To further complicate the picture, Universal Winding, which formerly made textile mill machinery but has diversified into fuel cells, nuclear power packs, etc., recently changed its name to Leesona Corporation. Leesona has concluded an agreement with United Aircraft Corporation giving the latter an exclusive license for a limited time to the use of Hydrox fuel cells for military and space applications.

Another hydrogen-oxygen cell that has received considerable attention in the technical press (21, 24) is the one developed by the National Carbon Company, a division of Union Carbide Corp. This cell uses porous carbon electrodes and operates at near ambient temperature and atmospheric pressure. Efficiency is stated to be 65–80 per cent.

Other organizations that have been working on hydrogen-oxygen cells include Allis-Chalmers, Chrysler Corporation, Electric Storage Battery Company, and the U.S. Army Signal Research and Development Laboratory.

Molten-salt fuel cells operate on gaseous carbonaceous fuels, such as carbon monoxide, water gas, producer gas, or methane. The electrolyte consists of a fused salt, commonly a mixture of alkali carbonates. The fused mixture may be contained in a porous, nonconducting MgO matrix. This type of cell offers the best possibilities for large scale power generation; it will be discussed further in the section on outlook for fuel cells in central station applications.

Consolidation Coal Company, General Electric, and Curtiss-Wright Corporation have been working on this type of cell.

Redox fuel cells are the type previously mentioned in which appropriate chemical intermediates are used to provide suitably fast electrode reactions. The intermediates are regenerated outside of the cell by reaction with the primary fuels.

In this country, General Electric has been using a titanium-bromine intermediate with impure hydrogen as fuel. At King's College (London), a similar system using a tin-bromine intermediate is being investigated. In this case, the fuel is coal. The only other American group reported to be working on this type of cell is the Missile Systems Division of Lockheed Aircraft Corporation. (10, 22) They have claimed better than 80 per cent efficiency, but no details of their cell have been disclosed.

A regenerative fuel cell, in which the reactants are continuously regenerated, is considered feasible if a cheap source of energy is available for the regeneration. The only regenerative cell reported to date is one developed by the Mine Safety Applicance Research Corporation. Lithium hydride reacts in a LiF–LiCl eutectic mixture at 450 C, and the products is decomposed, regenerating the reactant, at 850 C.

Another type of fuel cell is the *consumable electrode cell* which takes its name from the use of a consumable anode of alkali or alkaline earth metal. The cathode may be a solid electrode of organic material mixed with graphite or a porous carbon electrode through which oxygen or another oxidant may be introduced into the cell. This type of cell is characterized by low operating temperatures and high power to weight ratios.

National Carbon Company has been working on such a cell using sodium and oxygen, while Aerojet-General Corporation is developing a similar system based on zinc and chlorine. RCA, Armour Research Foundation, and Dow Chemical are also reported to be working in this field.

Development of an *ion exchange cell* has recently been announced by General Electric. (11, 14, 16) The cell uses hydrogen and oxygen and operates at room temperature and atmospheric pressure. An ion exchange membrane acts as a solid electrolyte in maintaining the electrolyte concentration. Electrolyte ions are attached to the membrane and cannot be leached from the cell; the membrane also rejects water when it reaches saturation, so there is no problem of electrolyte dilution.

Thermal efficiencies are reported to run as high as 60 per cent. Use of the membrane permits an especially light weight, small volume design, which points to the use of this device in military and space vehicle applications.

Fuel Cells in Central Station Applications

A high temperature fuel cell with molten alkali carbonate electrolyte and operating on gaseous carbonaceous fuels is the most promising fuel cell type for large scale power production. These cells operate at atmospheric pressure in the temperature range of 900–1600 F and use air as oxidant, rather than oxygen.

It has been estimated that the fuel cost for such a cell operating on natural gas might be less than 2 mills/kwhr. (23) Investment and operating costs are difficult to establish at present. These depend on the cost of

individual fuel cell elements and their life. Many of the fuel cell components are not in mass production, so their cost is not realistic. Cell life has been demonstrated to be at least six months, and this can probably be improved.

Another factor affecting the economics of fuel cell operation is the cell output per unit of electrode area, i.e., the current density at a given voltage. Consolidation Coal Company workers (20) have obtained 35 amps/sq ft. at 0.75 v. They feel that further cell development can yield 200 amps/sq ft at the same voltage. This would be close to what might be necessary for commercial operation if the cell life was sufficiently long.

The same workers have calculated overall thermal efficiencies for the conversion of fossil fuel to electrical energy. Based on experimental work on fuel cells and on coal gasification, the following figures were obtained for an integrated coal gasification and fuel cell process. An efficiency is also included for operating the fuel cell directly on natural gas.

Fuel Gas Source	Thermal Efficiency, per cent
Coal devolatilization by hydrogenation	60
Complete coal hydrogenation	70
Complete coal gasification with steam in indirect heat exchange with cell operation	75
Natural gas	65

The question naturally arises as to when high temperature fuel cells might be expected to be practical for commercial power generation. Probably the best statement of the present prospects was recently given by Liebhafsky and Douglas of General Electric, (23) who stated that "within five years it should be known whether it is wise to engage in the greatly expanded effort necessary to develop this cell for the generation of electricity on a central station scale . . . Neither this, nor any other fuel cell, will replace conventional central stations in the foreseeable future."

Thermionic Converters (26–35)

Description of the Method. The simplest form of thermionic converter is essentially a diode vacuum tube. Application of heat to the cathode "boils off" electrons from the electrode surface by imparting sufficient energy to some of the electrons to enable them to surmount the work function potential barrier at the surface. The electrons flow to the anode, where they are supplied to the external circuit. The anode must be kept relatively cool to prevent back current electron emission from this surface.

As in other vacuum tube applications, a problem is created by the space charge barrier formed by the cloud of electrons between the electrodes. If this charge is not neutralized, it will repel other electrons emitted from the cathode and eventually limit the current flow between the electrodes. One way of reducing the space charge barrier is to reduce the spacing between the electrodes. Within practical limits, this is almost always done. In addition, it is common to neutralize the space charge by introducing positive ions, e.g., Cs vapor.

A second problem posed by thermionic converters is the fact that they produce low voltage, high current d.c. For example, a 1 kw unit might produce 1000 amps at 1 v. One method of stepping up the voltage involves connecting a number of units in series so that the individual outputs are additive. Alternatively, current modulation within the converter may be used to produce an a.-c. output voltage. This a.-c. output from a group of converters connected in parallel could then be stepped up with a transformer. The current modulation could

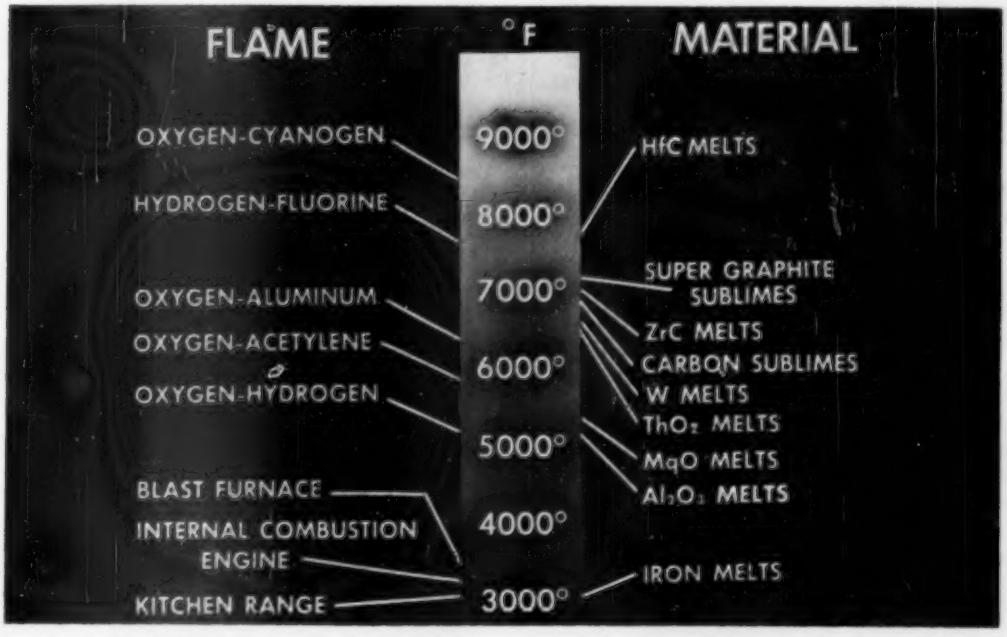

Fig. 3—Flame temperatures of several well known gases and melting points of various metals

be carried out by inserting a grid in the tube and feeding a modulating signal to the grid.

Current Developments

V. C. Wilson of the General Electric Research Laboratory has been active in the development of thermionic converters. He has described (26, 35) a device in which two molybdenum electrodes are enclosed in a glass tube containing gaseous positive ions. The cathode temperature is about 2500 F, while the anode is at about 1250 F. A similar device has been developed by Professors J. Kaye and G. N. Hatsopoulos of MIT. (27) Both of these converters have attained thermal efficiencies of 10–12 per cent. The MIT workers believe that it will be possible to build a power plant utilizing thermal converters that yield 5000–15,000 w/cu ft of plant volume. They state that this figure would be satisfactory for small power plants.

The first direct conversion of nuclear energy to electricity was achieved at the Los Alamos Scientific Laboratory in April 1959, using the Los Alamos "plasma thermocouple." (28–32) This consists of a thermionic cell which was placed in the core of a 5 Mw (th) nuclear reactor. An open circuit voltage of 3.8 v and a short circuit current of about 35 amps were obtained. The unit operated at a thermal efficiency of 17 per cent, but the laboratory expects to improve this to around 30 per cent.

Future Outlook

Theoretically, a thermal efficiency of 35 per cent should be attainable with thermionic conversion devices. Practically, most workers expect efficiencies of 25–30 per cent to be reached. Such efficiencies will require a heat source of approximately 2000 F. This is about twice as high as current reactors can go. However, it is expected that nuclear technology will develop to the point that such temperatures will be available from nuclear sources.

A nuclear heat source would be advantageous for thermionic converters, since gamma radiation from the nuclear source is expected to help minimize space charge effects. Materials are available with good thermionic properties that can also withstand high temperatures and high radiation fluxes.

With an inlet temperature of about 2000 F and an outlet temperature of the order of 1000 F, it is attractive to consider the possibility of thermionic conversion in a nuclear reactor followed by a conventional turbogenerator. The overall thermal efficiency of such a plant is expected to be as high as 50–60 per cent (30), although some workers (33, 35) more conservatively predict about 45 per cent.

Thermoelectric Generators (36–47)

Discussion of the Method. This method of generation depends on the use of thermoelectric materials capable of producing an electric current when heated. The Westinghouse Research Laboratories have been particularly active in the development of such materials.

It has been found that mixed valence compounds (oxides, sulfides, selenides, or tellurides) of transition metals (Mn, Fe, Co, or Ni) in which a charge carrier has been incorporated are effective thermoelectric materials at elevated temperatures. An example is $Li_z^{+}Ni_{1-2z}^{++}Ni_z^{+++}O$. Lithium ions are introduced into the NiO lattice as a charge carrier. Since oxygen atom wants to acquire two electrons, every lithium ion introduced results in a remaining Ni (II) ion becoming a Ni (III) ion. About 8 per cent of the transition metal ions are replaced by lithium ions.

These mixed valence compounds have several advantages over other thermoelectric materials. They are prepared from relatively abundant and inexpensive materials. They are of a ceramic nature and can be used at high temperatures without decomposing or reacting. They are not susceptible to traces of impurities, and they do not deteriorate on exposure to radiation.

More recently, Westinghouse has developed a new thermoelectric material, an indium arsenide phosphide semiconductor. The operating range of this material is 850–1500 F. It fills a gap in the spectrum of thermoelectric materials, since it operates at temperatures above conventional semiconductors but below the 2000–3000 F range of the ceramic-like, mixed-valence compounds.

Current Developments

Thermoelectric devices of various types are under development at the present time, as indicated in the following paragraphs.

The U. S. Navy Bureau of Ships has contracted for 5000 w thermoelectric generators to be built by Carrier Corporation and by Westinghouse. The units are expected to be in service by mid-1960. The heat source will be diesel oil or other fuel readily available to the Navy. The temperature of the cool side of the generator will be maintained by water cooling. Sea water will be used directly if possible; otherwise, fresh water, cooled by sea water in a heat exchanger, will be used. For naval applications, thermoelectric generators are particularly suitable, since the absence of moving parts makes detection more difficult.

Westinghouse has also received a Navy contract to build a thermoelectric unit combining an air conditioner, space heater, and refrigerator-freezer in a single system. This unit will be tested for shipboard use.

A thermoelectric generator has been developed by Westinghouse for the Air Research and Development Command that is at least ten times larger in electrical output than any similar device ever built in the U. S. It also has three times more power per pound than any previous generator of this type. The unit weighs 40 lb and has been designated TAP-100 (terrestrial auxiliary power, 100 w). The unit operates at 850 F. The present model burns propane, but gasoline or kerosine could also be used. Westinghouse is working on another model that will be fueled by radioisotopes.

Boeing and Westinghouse have jointly developed a solar-powered thermoelectric generator. The device weighs 3 lb, is 20 in. long, and produces 2.5 w of power. Its size and weight make it suitable for use in space vehicles, e.g., as a power source for radiotransmission.

Future Outlook

Clarence Zener of Westinghouse Research Laboratories has predicted (36, 45) that, within the foreseeable future, thermoelectric generators will operate with efficiencies as high as 35 per cent. This efficiency would be obtained by careful selection of a series of thermoelectric materials,

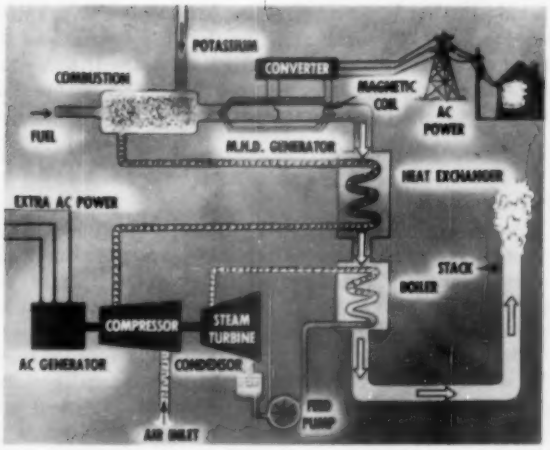

Fig. 4—Magnetohydrodynamic open system using fossil fuels. Products of combustion replace helium-cesium mixtures in conventional MHD units

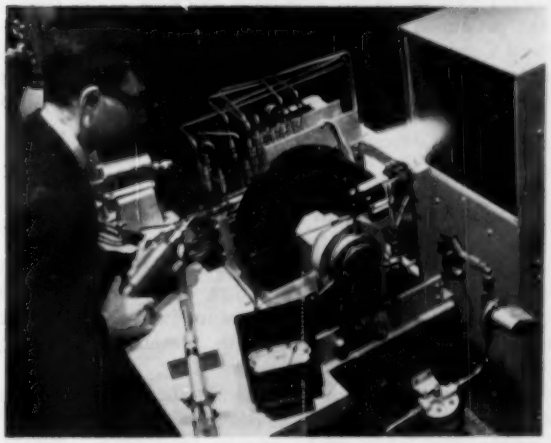

Fig. 5—Dr. Emmerich, Westinghouse physicist demonstrates experimental magnetohydrodynamic generator with output equivalent to one watt

each of which gives a maximum electrical output in a certain temperature range. These materials would then be used in a series of stages to cover any desired range from about 3500 F down to ambient temperature. Each stage of such a generator would receive the waste heat discharged by the previous stage.

Westinghouse spokesmen have indicated (43) that they do not expect thermoelectric power to make obsolete present methods for large-scale power generation. Rather, they expect thermoelectric generation to supplement conventional methods and find application on the basis of efficiency and economic considerations.

In conventional power generation, efficiency increases with power rating. The efficiency of a thermoelectric generator, however, is determined only by the Carnot cycle and the efficiency of the thermoelectric material; it is independent of the size of the generator. Therefore, below a certain critical power rating the thermoelectric generator is more efficient than conventional generation.

Once the technology is well developed, it should be possible to manufacture thermoelectric generators, which have no moving parts, more cheaply than conventional generating systems. Where capital cost is the predominant factor, as when the use factor is low, as in auxiliary power units, thermoelectric generators should be attractive.

With the above considerations in mind, it may be seen that thermoelectric generation is especially suitable for certain applications. One such case is for use in remote locations, e.g., for communications systems where conventional power sources are not available and when batteries are not practical. Another application is for stand-by emergency power supplies. It is also possible to design thermoelectric generators to operate on solar energy or on waste heat in stack gases, utilizing thermoelectric materials sensitive in the low temperature ranges available for these sources. In quite a different temperature range, a thermoelectric generator might operate on rocket exhaust gases.

Magnetohydrodynamic (MHD) Generation (48–51)

Discussion of the Method. This method generates electricity directly from hot gases by passing a high temperature gas stream at high velocity through a strong magnetic field. An MHD generator has no moving parts and operates at temperatures high enough to ionize the gas to a plasma. The lines of force of the magnetic field divert free electrons into the external circuit. In other words, this method of power generation involves the familiar principle of moving a conductor (which in this case is the high temperature, highly ionized gas stream) through a magnetic field.

The power plant cycle visualized (51) combines an MHD generator with a conventional generating system in a manner analogous to a combined gas turbine-steam turbine cycle. The high operating temperatures yield an expected heat rate of about 6200 Btu/kwhr. Atmospheric air is compressed to 140 psi and heated to 3600 F in a regenerative air heater. The gas temperature is further increased to 5300 F in a coal combustion chamber and admitted to the MHD generator. Gas is exhausted from the MHD generator at 4200 F. It then passes to the regenerative heaters, is cooled to 2100 F and passes to the conventional boiler.

Current Status and Future Outlook

General Electric has operated an MHD generator with a plasma of air heated to 5000 F and obtained 1 kw of power for 5 secs. Thermal efficiency of this method is expected to be in the 40–50 per cent range, compared to about 35 per cent for conventional turbogenerators (48).

The G.E. workers believe (49) that it would be feasible to operate an MHD generator on rocket engine exhaust gases and that such a generator could be developed within two years. For general use, they predict that MHD power generation is at least 20 yr away.

Westinghouse has also built an MHD generator (52–54), which has produced 2.5 kw of power for as long as 4 min. The unit is designed for a capacity of 10 kw, but to date thermal damage to refractory lining materials has prevented operation at this power level. The combustion of furnace oil and oxygen produces a gas temperature of about 4600 F. To improve the gas conductivity at this temperature, an easily ionized potassium soap is dissolved in the oil as a "seeding material". The Westinghouse workers have also experimented with the combustion and oxygen, seeded with potassium.

The Avco-Everett Research Laboratory has demon-

strated (50) an MHD generator using an argon plasma that produced some 11 kw of power for about 5 secs. Avco Corporation has recently concluded an agreement with ten utilities to conduct an expanded research program on MHD generation. Major goals of this work include further basic research on MHD phenomena and development of suitable materials of construction to withstand the high temperatures involved. If this program is successful, the next step would be to build a small prototype plant for further development work.

Summary of Promising Methods

It has been indicated that fuel cells, thermionic converters, thermoelectric generators, and magnetohydrodynamic generators show promise for future use in large-scale applications. Briefly, the present outlook for these methods is as follows.

Despite a great deal of work in the field, fuel cells, especially hydrogen-oxygen cells, are not economically feasible for large scale power production. Smaller scale models, which operate on gaseous fuels, are currently being developed. If the ultimate goal of a fuel cell using pulverized coal and air rather than oxygen is reached, then fuel cells would certainly be a factor in central station power generation. When this goal may be attained or when large fuel cells operating on gaseous fuels may be economically feasible for power plants is problematical, but these developments are not expected to occur in the near future.

Thermionic conversion has distinct possibilities for successful utilization, especially in conjunction with nuclear reactors. Workers in the field consider that thermal efficiencies of 25–30 per cent will be achieved and that a combination of a nuclear reactor with thermionic conversion and conventional turbogenerator conversion might reach thermal efficiencies of 50–60 per cent. The time table for practial application of thermionic converters is not at all clear, however.

Thermoelectric generators will undoubtedly find a place in future power plant cycles, probably in conjunction with other methods. For example, they may operate on waste heat or on gas turbine exhaust as a supplement to conventional methods of power generation.

Magnetohydrodynamic generation is attractive from the standpoint of combining with conventional generation. This field has been little explored. General use may be 20 yr off, but the rapid pace of developments in high temperature gas work in connection with missile and space projects as well as increased work on MHD generation, could shorten this time.

One drawback to these methods for the direct conversion of heat to electricity is that they produce low voltage d.c., while a.c. is required for practical application. It has been estimated (51) that conversion to a.c. by mercury-arc rectifiers could be accomplished at a capital cost of $40/kw and with an efficiency of about 96 per cent. Other conversion methods were mentioned in the discussion of thermionic devices. Recently, the General Atomic Division of General Dynamics Corp. announced (55–57) the successful conversion of heat directly into a.c. using a high-temperature thermionic cesium cell. The current produced had a frequency of 100 kc/sec, but no difficulty was envisioned in producing 60 cycle current. At this stage, it is not known how this process would compare in cost to direct conversion of heat to d.c., followed by conversion to a.c.

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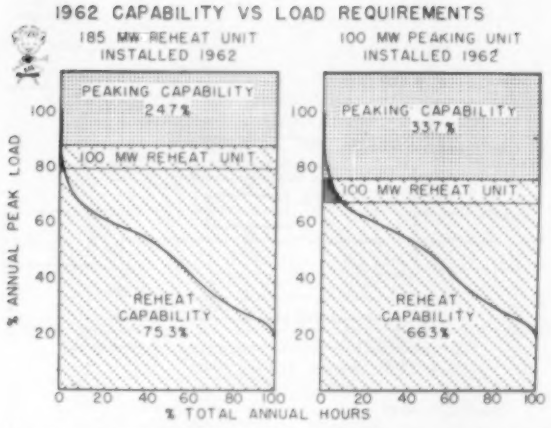
1962 CAPABILITY VS LOAD REQUIREMENTS
185 MW REHEAT UNIT INSTALLED 1962
100 MW PEAKING UNIT INSTALLED 1962
PEAKING CAPABILITY 247%
100 MW REHEAT UNIT
REHEAT CAPABILITY 75.3%
PEAKING CAPABILITY 337%
100 MW REHEAT UNIT
REHEAT CAPABILITY 66.3%
% ANNUAL PEAK LOAD
% TOTAL ANNUAL HOURS
0 20 40 60 80 100
20 40 60 80 100

Fig. 1—Above illustration indicates adherence to a program of 185 Mw reheat units at two year intervals would result in the majority of the available capability being reheat by 1962

By WILLIAM J. BURNS†

Long Island Lighting Company

Mr. Burns presents a keen analysis of the peaking problem with special emphasis on the instrumentation required for each of the projected solutions.

Instrumentation for Peaking Capacity*

PEAKING capacity is a topic currently of prime interest to many utilities. Various approaches are being made to the problem of providing system additions for meeting maximum demands. For example, some companies, such as American Electric Power and Union Electric, have plans for pumped storage. Generally, however, nature has not provided the topographical and hydrological features essential to this type of installation and alternate solutions must be applied. Maine Public Service and others have installed diesel generators. The application of gas turbines also is being investigated actively by the industry. Development work is underway on dual incremental peaking turbine generators designed for base load operation and capable of substantial additional output for short periods of time at some sacrifice in efficiency. Finally, low cost steam electric plants have been considered and in certain instances found attractive from an economic viewpoint.

Need for Peaking Capacity

The need for additional peaking capacity is not universal but depends upon factors peculiar to each individual system. In the case of Long Island Lighting Company the characteristic of the electric load is such that a sharp peak occurs, presently reaching a maximum in the winter. The severity of this peak load is such that the top 20 per cent of the load lasts only 140 hr per year. This condition pertains currently despite the fact that summer loads have been rising and may match the winter peak in the foreseeable future.

To date the problem of providing generation for peak loads has been resolved by utilizing our older, less efficient units. Rapid improvements in steam plant efficiencies have made it economical to install reheat equipment for base load operation, with the result that our rapid load growth in the last decade, which has required that we more than triple our capacity, has been met by installing high pressure, high temperature reheat units. However, we now find that our system heat rate has leveled because of the large amount of highly efficient capability installed and that further additions of highly efficient equipment will do little to improve the system heat rate.

Adherence to a program of installing 185 Mw reheat units at two year intervals would increase our reheat capability to more than 75 per cent of the total capability by 1962. As illustrated in Fig. 1, relatively new, efficient equipment would be relegated to peaking service. By installing 100 Mw of low cost peaking generation in 1962 the load factor on equivalent reheat capability would be improved. In addition, present worth savings in excess of $3,000,000 appear realizable by delaying installation of a large reheat machine for one year.

Economic loading studies have been made to substantiate the justification for seriously considering installation of peaking capacity. We have found that over a ten year period the projected capacity would operate an average of 250 hr per year for annual peak loads and maintenance outages of other units. These limited hours of operation establish that the major criterion in selection of peaking generation for our system must be one of minimum investment even at a sacrifice in efficiency, provided there is no sacrifice in reliability of operation.

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Installations Considered

As a basis for our investigations we have sized the peaking plant to be equivalent to our annual load growth and related reserve requirements, or approximately 100 Mw. To provide this capability we have considered diesel generators, gas turbines and steam electric units with cost estimates being predicted upon 1962 operation. In our reviews close attention has been directed to the instrumentation for each of these types of peaking capacity. The salient features that have been determined are summarized below.

Diesel Generators

In our analyses we have credited diesel generators with outstanding control flexibility. Our review of the design features and field investigation of operating units have concluded that unattended, remotely operated, fast responding generation can be obtained. The base plant we have considered consists of multiple blocks of four 2000 kw supercharged machines coupled to a common electrical control center.

Each power unit contains a synchronous generator with a regulated static type exciter, directly coupled to an engine having the necessary oil coolers, filters and engine cooling system. A 100 gal fuel tank on each machine is supplied from a central, large storage tank, with provisions being incorporated for protective action and indication for improper fuel level conditions. During shutdown periods when the plant is on standby, engine temperatures are kept ready for fast starting by means of thermostatically controlled electric heating and means for recirculating oil and water to maintain proper conditions.

By means of the instrumentation furnished as an integral part of the plant a single pushbutton station, located as desired, is sufficient to initiate start up and shutdown procedures for the total block of capacity. Normally, the basic four unit plant is designed to operate at its full rated capacity of 8000 kw. The added expense of providing for load sharing between generators or partial loading of individual units is not considered essential for peaking operation. The additional equipment required for dead load pickup has been included in our layouts.

Fig. 2 shows a block diagram of the automatic control system which will sequence the connecting and disconnecting of the various systems required for operation of the plant, provide protection of itself and the systems against abnormal operation, and supply appropriate indications when such operations have occurred. Upon receipt of a single impulse signal, derived from an external source, the instrumentation will start the individual generating units by successively moving each engine from a static condition to an rpm sufficient to allow it to reach self-sustained firing speed. The battery operated starting motor is disconnected when signaled by an engine speed sensing device. As soon as the first engine has fired a crank signal initiates the sequence for the second engine, etc., until all units are operating. Machines are synchronized with the line, each breaker closed and the units loaded to full load successively. A magnetic amplifier type regulator with auxiliary controls regulates the voltage to permit operation of the plant in parallel with the transmission system. Com-

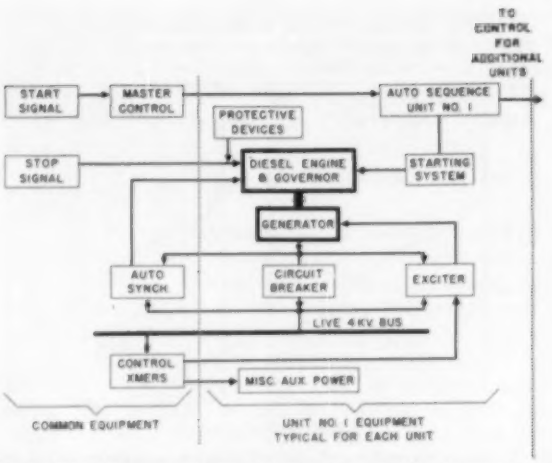


Fig. 2—Block diagram of automatic control for a diesel generator to permit connecting, disconnecting, protection and supply warning signal

bination differential protective relays protect the individual generators and the main power bus. Surge capacitors and lightning arresters also are provided.

The abnormal conditions that will be detected and for which corrective action will be taken included conditions of: external fault; reverse power; voltage surges; overvoltage; ground or phase fault; and unit field overcurrent. In addition to operation of the protective relaying, the engine will shut down automatically in the event of excessive cooling water temperature, low lubricating oil pressure and high lubricating oil suction. An annunciator indicates the reason for the shutdown.

Metering equipment includes an a-c voltmeter, a-c ammeter, kw meter, kvar meter, frequency meter and kwh meter. Selective switching permits each of these devices, except the Kwh instrument, to meter individual power units or the total group.

A complete control station averages about 15 per cent of the total installed cost for diesel generator peaking capacity. This amount does not include extension of the controls to a point beyond the plant location but does include all switchgear, line circuit breakers, auxiliary power transformers, and a battery and battery charger. A cost breakdown would have little significance, because the control unit is available only as a complete package.

Application of complete automation to the diesel generator plant, coupled with the inherent characteristics of the prime movers and electrical accessories, makes possible the attainment of full output of the plant in 90 sec. Thus there is the possibility that in addition to furnishing peaking capability there might be reasonable argument that the capacity can be treated as spining reserve even though idle.

Gas Turbines

Rivaling the diesel generator from the standpoint of completely automatic operation is the gas turbine plant we have studied. An installation of two simple cycle, distillate oil fired gas turbines having a combined winter output of about 50 Mw has been established as the basic plant for review purposes. The station design, which incorporates instrumentation for local operation as well as supervisory equipment for remote unattended operation, permits expansion of the installa-

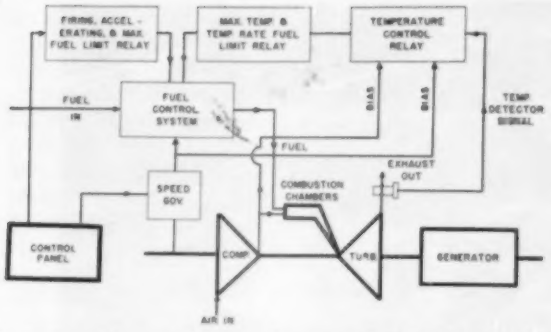


Fig. 3—Gas turbine control diagram shows a number of actions take place when the starting signal is given. See text for details

tion to a four unit plant or construction of an identical two unit plant at another location to produce the desired 100 Mw of peaking capacity. All electrical equipment essential to control has been located on the operating floor. For each unit the gas turbine, generator and main exciter are direct connected. The inlet and exhaust silencers have been selected to satisfy local conditions and silencer size, attenuating characteristics and effect on output have been considered in relation to the noise level requirements.

The plant is designed to be completely self-protecting under all conditions of electrical or mechanical malfunction. For unattended operation, starting and stopping of the units would be initiated from a remote point by means of code selector supervisory control. As shown by the control diagram, Fig. 3, when the starting signal is given various operations occur automatically. The auxiliaries that are energized are the auxiliary lube oil pump, vapor extractor, control air compressor, main cooling water valve, fuel supply pump, ventilation fans and ventilation louvers (to open). Interlocks in the turbine master starting relay verify that all essential auxiliaries are established and the turbine starting sequence is thus initiated. The turning gear starts and the cranking motor accelerates to firing speed. After a purge period the turbine is fired. The cranking motor then accelerates the unit to self-sustaining speed and shuts down, while the turbine continues acceleration to rated speed. When the starting sequence is completed the automatic synchronizing equipment is activated to adjust speed and close the generator breaker when the generator and system voltages are in phase. When the breaker is closed the governor synchronizing motor automatically is operated to the maximum load position, which places the turbine under exhaust temperature control. Maximum output will be maintained for the existing ambient temperature.

The above operations do not require the attention of an operator, although company policy might dictate the presence of at least one man in the plant at all times. Conditions which could lead to equipment damage are instrumented to trip the unit. Included in these classifications would be turbine overspeed, loss of flame, failure to fire on start, high exhaust temperature, vapor extractor not running (after a time delay), high lube oil temperature, low lube oil pressure, incomplete starting sequence, excessive vibration, high bearing cavity temperature, high thrust bearing oil drain temperature and generator trouble resulting in generator breaker operation.

Incipient conditions, such as those which would reduce plant output, sound an alarm. The alarms and trips are all indicated by the annunciator on the gas turbine control panel in the station. At the remote operating point a single light indicates annunciator operation and requires the dispatching of a man to investigate.

The cost of the instrumentation for the completely automatic remotely controlled gas turbine plant described above amounts to about 4 per cent of the total installed cost. The basic design is predicated upon complete automation; consequently, it is unlikely that any savings would result from the substitution of manual for automatic control of any or all of the starting, running and shutdown operations. The remote control equipment included in the above figure amounts to about $^3/_4$ of 1 per cent of the total plant cost.

Dual Incremental Peaking Turbine Generators

In addition to diesel generators and gas turbines we have reviewed the dual incremental peaking steam turbine generator as an attractive means of providing peaking generation. Equipment to provide efficient base load capacity for normal operation, plus, at a higher heat rate, better than 50 per cent of the base capability as additional output, is being developed by the manufacturers of turbines and boilers. Two approaches are being pursued. In one instance the design of the dual unit is predicated upon increasing the throttle steam pressure to accommodate the overload condition. An alternate design incorporates bypassing of the high pressure section of the turbine and supplying an increased quantity of reheated steam to the low pressure end of the turbine to increase the output.

The instrumentation for these innovations has not been reviewed in detail in our study, for development has not progressed to the point that serious consideration could be given to purchase of a unit for installation in 1962. However, the dual unit is viewed favorably as a potential source of low cost peaking capacity, for present indications are that a combination unit designed for a base output of 180 Mw and a peak load output of 250 Mw may provide peaking capacity at an incremental cost per kw of about one-half the cost per kw of a base load reheat machine.

Low Cost Steam Electric Plant

While the Long Island Lighting Co. has given serious thought to the above methods for providing peaking capacity, more detailed investigations have been centered around low cost steam electric peaking units. Cost studies have demonstrated that a low pressure, low temperature installation which would include minimum heat recovery equipment, limited structures, and single auxiliaries compares favorably in cost with the other proposals analyzed.

With cost differentials thus discounted, and after taking into account location, number and complexity of units, noise, operating experience, and other factors we have concluded that a steam electric installation would be the most suitable for our requirements.

Evaluation of steam cycles has shown that the minimum cost plant would be achieved using an 850 psig,

Fig. 4—Plant layout at the Edward F. Barrett Station, Long Island Lighting Co., demonstrates the way in which a 100 Mw low cost steam generator could go in near the existing 185 Mw unit and not limit further expansion

900 F non-reheat steam turbine, an oil fired, pressurized steam generator, with one forced draft fan and no air heater, one feedwater heater and single, full size boiler feed, condensate and circulating water pumps. The best heat rate of such an installation would be expected to be about 14,000 Btu per kwhr., but the total fuel consumption would be low because of the anticipated limited operating period.

Analyses of available sites have determined that Edward F. Barrett Station, an existing site containing one 185 Mw reheat unit would be preferred because existing transmission facilities are capable of accommodating an additional 100 Mw without supplementary outlets, whereas at other possible locations added transmission costs would be involved. As shown in Fig. 4 a 100 Mw peaking unit could be located adjacent to, but distinct from Unit 1, the 185 Mw reheat unit, so as not to limit the extension of the existing plant. By utilizing a compact design two 100 Mw peaking units could be placed within the span of the existing crane. Interconnections between Units A and 1 would be limited to air, service water and condensate for emergency needs. Enclosures around the unit would be minimized, for the plant would be of the outdoor design as has been our practice for the past decade with any siding being lightweight aluminum. Fig. 5 indicates that the turbine pedestal would not provide lay-down space and during overhauls, parts would be placed on the paved area between machines or upon the Unit 1 deck. By locating the turbine as close as possible to the boiler, an enclosure encompassing the turbine standard and the oil burners is formed suitable for containing the main control board, the recorder and relay board, the 4 kv switchgear, the 480 v motor control center and a 480 v 500 kva transformer. It is anticipated that the unit would be capable of being cold started, operated and removed from service by two operators. Selection of centralized control over decentralized control is indicated on the basis of minimum installed cost. There would be no local control stations, all 4160 and 480 v motors being started directly from the switchgear in the control room.

To keep costs to a minimum the turbine would be sized to utilize all available capacity of the last stage blading which means exceeding the normal design factors applied to conventional turbines. Generator size would be reduced by specifying a minimum short-circuit ratio of 0.50 and a power factor of 0.95, and by taking into account the cooler hydrogen to the generator windings afforded by the low temperature of the cooling water during the winter period. The condenser would be sized for a turbine backpressure of 3 to $3^1/_2$-in. of mercury under winter conditions and 6 to $6^1/_2$ in. of mercury in the summertime. The slightly reduced output of the peaking unit under summer conditions would be tolerated. Major areas of cost reduction on the boiler would be: fuel burning facilities for heavy oil only, pressurized furnace, high furnace heat release rates

at maximum load, no regenerative air heater, single forced draft fan, no induced draft fan, no dust collector, and location of the stack close to the boiler gas outlet. A major cost reduction would be achieved by utilizing the existing Unit 1 starting transformer for starting and auxiliary power for the 100 Mw unit. Miscellaneous additional savings in electrical equipment would be realized by providing only single controls for all motors from the switchgear or the 480 v motor control center in the operating area.

Design Criteria for Peaking Capacity

Because initial operating and design of the steam power plant for only peaking service imposes conditions which are unique, the following considerations would be encompassed in both the plant design and equipment guarantees:

1. Average annual operating time of 250 hr ranging from 1000 to 50 hr per year.
2. Average of 50 start-ups per year with minimum start-up and shutdown time.
3. Recognition of the fact that layup periods would range from overnight to many months.
4. Anticipated maintenance scheduling of minor overhauls every five years and major overhauls every ten years.
5. Suitability of equipment for continuous operation for extended periods if required.

Instrumentation for Steam Electric Peaking Units

Instrumentation and controls for the steam peaking unit would be considerably reduced from that normally installed in a conventional centrally controlled steam plant. This would largely be a result of the fact that the peaking unit would be a more simplified compact unit.

The simplicity of the cycle to be controlled and therefore the small amount of control equipment needed is demonstrated in Fig. 6 which shows the flow diagram for the 100 Mw unit. Limiting the number of auxiliaries to be installed and limiting their control to a single location directly on the switchgear compartment would further reduce the quantity of control equipment required.

These plant design features would permit development of the compact control board shown in Fig. 7. The length of this board would measure only 12 ft as contrasted with the 36 ft long complex board for one of our coal fired, 185 Mw reheat units. Moreover, there would be only about 150 controllers, indicators, recorders and annunciators required for the peaking unit control board whereas almost 400 are installed on the control panel for the conventional unit. Annunciators would comprise about 70 of the items on the peaking unit control board and 130 of those on the reheat unit control board.

For the same reasons the number of plant instruments and controls could be reduced from more than 500 to about 200. Included in these totals are all pressure gages, thermometers, thermocouples, resistance elements, test wells, solenoid valves, float switches, pressure switches, and control valves. The number of wells for test thermometers and pressure taps for precision test pressure gages could be reduced considerably because extensive plant performance tests to check efficiency would not be warranted for a low efficiency plant designed for short duration peaking service only.

A further reduction in plant equipment would be achieved by elimination of bypasses around control valves. However, all valves would be provided with means for local hand control.

The estimated cost of instrumentation for the 100 Mw steam electric peaking unit would amount to about $2^{1}/_{2}$ per cent of the total installed cost. This percentage does not differ materially from that experienced for a 185 Mw reheat unit. However a comparison of these costs on the basis of $/kw indicates that the peaking unit instrumentation and control cost would be less than one-half that for the reheat unit.

While many reductions have been contemplated in the quantity of instrumentation and controls, conventional equipment would be employed almost exclusively.

As customary in the Long Island Lighting Co.'s plants, both the boiler feedwater control and the combustion controls would be designed for automatic operation with remote manual control from the main control board. Feedwater flow from the single constant speed motor driven boiler feed pump would be regulated by an air operated valve actuated by a three-element control system similar to that installed on our reheat units. The combustion control system, which would be simplified because only heavy oil would be burned, also would be a conventional system employing the usual fuel oil control valves, safety interlocks and alarms for supplying mechanical atomizing oil burners. The system would be designed for automatic operation from full load down to 10 per cent load. Fuel flow would be

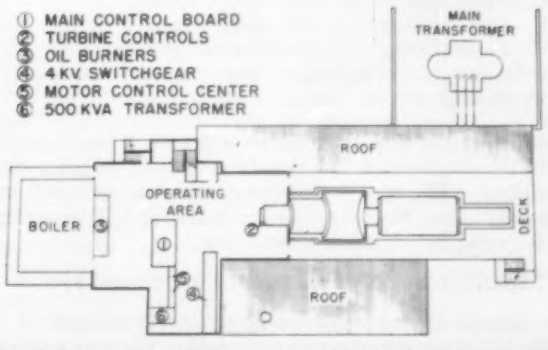


Fig. 5—Close quarters for an outdoor plant design indicates turbine pedestal would not provide lay-down space so area between machines would be used during overhauls

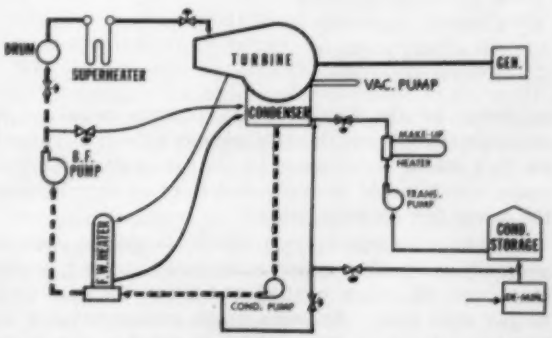


Fig. 6—Flow diagram for a 100 Mw low cost steam generating unit emphasizes its simplicity and hence its low control requirements

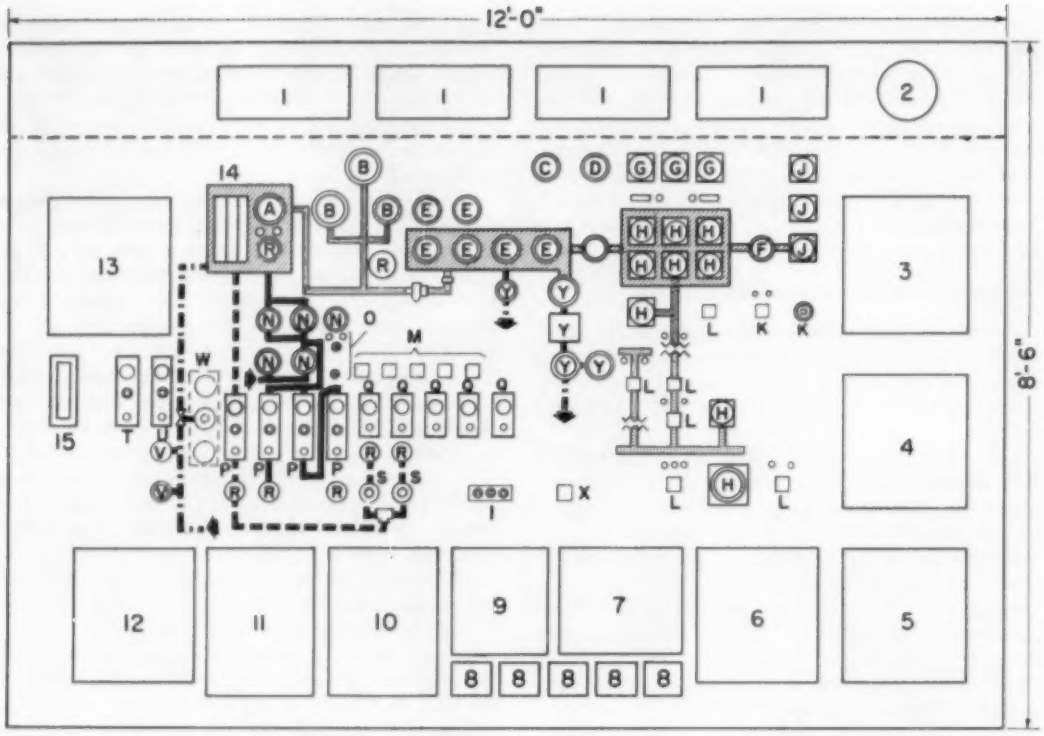


Fig. 7—The simplified, compact peaking boiler with its straight-forward cycle, Fig. 6, gives a much desired compact control board

Panel Instruments and Controls

1—Annunciators
2—Clock
3—Generator load
4—Generator hydrogen temperature
5—Generator stator field and transformer temperature
6—Cooling water and turbine lube oil temperatures
7—Vibra amp and shell differential
8—Power units
9—Speed, valve position and eccentric
10—Feed flow and steam temperature
11—Boiler performance
12—Conductivity
13—Steam temperature
14—Boiler drafts
15—Drum level gage
A—Boiler drum pressure
B—Throttle conditions
C—Air supply pressure
D—Hydrogen pressure
E—Turbine operating pressures
F—Generator lube oil pressures
G—Synchronizing meters
H—Generator conditions
J—Exciter conditions
K—Exciter switch and rheostat
L—Switches and rheostats
M—Valve positioning switches
N—Burner and ignition pressures and temperature
O—Firing system safety indicators
P—Combustion control manual-auto relays
Q—Manual control relays
R—Position indicators
S—Air flow ratio and min. air flow relays
T—Boiler feed pump recirculation relay
U—Condensate pump recirculation relay
V—Recirculating valve position indicators
W—Auto-manual feedwater control relay
X—Emergency trip switch

regulated by the master steam pressure regulator to maintain the 850 psig throttle pressure as load is changed. Air flow would be regulated by the forced draft fan inlet vanes which would be controlled from an impulse from the steam flow metering nozzle.

Interstage desuperheating sprays would be used for manually controlling superheater outlet steam temperature from the main control board for the top 10 to 15 per cent load. At lower loads remote manual adjustment of excess air would be provided.

Condenser vacuum control would be a completely automatic pushbutton operated system using a single electric motor operated vacuum pump for hogging and holding. The unit would be a complete compact assembly containing all valves, controls, air leakage meter, etc., mounted on a single base plate.

Special Features of the Steam Plant Control System

Several special provisions have been contemplated in the 100 Mw steam plant for adequate condensate makeup despite only a few hours daily operation, to accommodate lay-up periods ranging from overnight to several months,

and for either rapid or controlled type start-ups.

The steam peaking plant condensate makeup requirements would be particularly severe because of the large number of start-ups and the short duration of operation. The first condition would require that more makeup be provided than for a base load unit while the second condition would limit the operating time for a makeup system which could produce only while the plant is in operation.

To meet these conditions there would be a package type two bed demineralizer which could be placed in unattended automatic operation entirely independently of operation of the peaking unit. Selection of this type of system would offer considerable savings over an evaporative system because it could be sized at a much smaller capacity for 24 hr operation.

Operation of the demineralizer system would be controlled by the water level in a 60,000 gal condensate storage tank. The flow of city water through the demineralizer system would be regulated to maintain an effluent purity of 1 ppm total solids and 0.1 ppm silica. Regeneration of the demineralizer beds would be controlled automatically by a conductivity cell located at the demineralizer outlet and a totalizing water meter. An increase in the discharge condensate impurities above the limiting values or a predetermined total raw water flow would actuate a program cycle controller for automatic regeneration. Upon completion of the regeneration cycle, the demineralizer would be returned automatically to normal operation.

Since selection of the demineralizer system would be based on unattended operation independent of the peaking unit, remote observation for detection of operating faults would appear necessary. This would be accomplished by placing an annunciator in the nearby 185 Mw reheat unit control room which is attended at all times.

In addition to the demineralizer, there are several other systems requiring remote observation. The generator would be filled with hydrogen for all but prolonged layovers so that a hydrogen system remote annunciator would be required.

Peaking unit room temperature would also be monitored by an annunciator in the Unit 1 control room in order to detect failure of the heating system and potential freeze-up while shut down during winter months. Similar remote annunciators would be provided to detect failure of operation of strip heaters in outdoor electric motors and for fire alarms in the peaking unit.

During the peak load operating period in winter months the peaking unit would be called upon for frequent daytime operation. Operating savings would be realized by designing the plant for rapid start-up and minimum start-up heat losses.

Specifications for all major equipment and control equipment would include these requirements. The steam generator would be provided with special thermocouples in the boiler drum to observe drum skin temperatures while starting. For overnight shutdowns, rapid start-up of the boiler would be insured by providing remote manually operated dampers at the forced draft fan discharge and the stack inlet for bottling up furnace heat. This provision would also minimize starting losses which would be relatively small in comparison to a large reheat unit because there would be less equipment to be heated to operating temperature in the compactly designed peaking unit.

The turbine generator, which would be provided with all the standard complement of control and supervisory instruments, also would be provided with special thermocouples in the high pressure turbine shell to observe temperatures during the start-up period. As would be the case with the boiler drum, start-up time would be dictated by the maximum allowable thermal stresses in the heavy-walled parts. Since starting temperatures would depend upon the duration of the shutdown period, the minimum safe start-up time could be achieved.

Summary

Instrumentation for various types of peaking capacity has been reviewed. Diesel generators and gas turbines are designed basically for completely automatic operation. This feature makes this capacity particularly adaptable to utilization at outlying points on the transmission system where possible deferment of additional transmission as well as peaking capacity enhances the economic aspects. However, for bulk peaking power located at a central station site the low cost steam electric plant appears to offer certain superior advantages at this time. What form installations considered in future analyses will take is indeterminate, but the dual incremental peaking turbine generator probably will warrant close examination.

Dresden Achieves Full Power

Commonwealth Edison Company's Dresden Nuclear Power Station, the nation's largest atomic power plant, demonstrated full-power operation for the first time, it was announced last June 30, sending 180,000 kw of electricity over transmission lines into Chicago and northern Illinois.

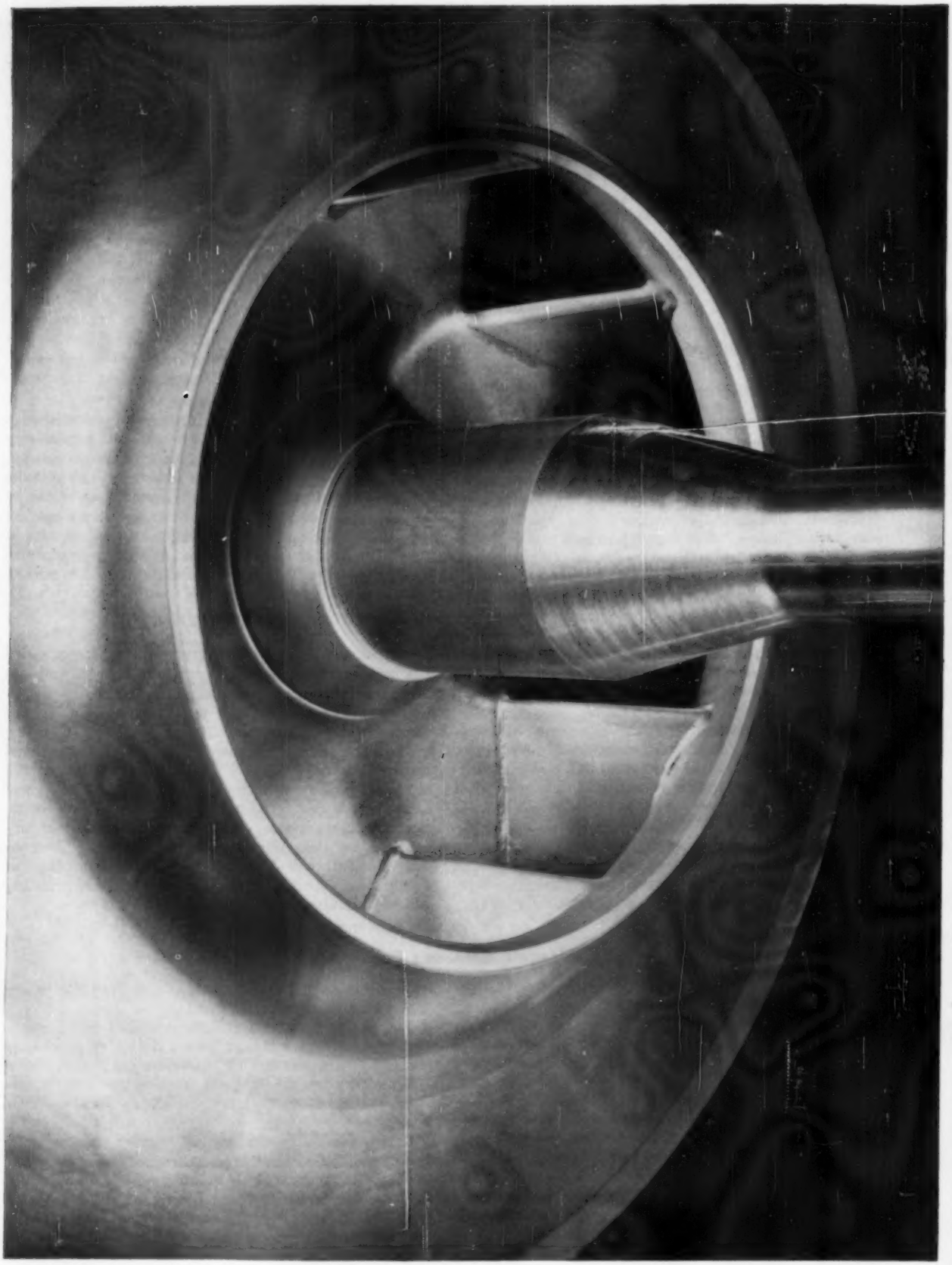
At full power the nation's first full-scale, privately financed station produces enough electricity to supply the needs of a city of more than 200,000 population.

After this demonstration, tests at various power levels will be performed.

Officials of General Electric Company, designer and builder of the 51 million dollar plant, called first full power a milestone which indicates atomic energy has at last assumed its place alongside coal, oil and gas, and hydroelectric as an important source of power for peacetime generation of electricity.

The achievement at Dresden, located 50 miles southwest of downtown Chicago, comes almost 18 years after the atomic age was ushered in here when Enrico Fermi achieved the first atomic chain reaction under the stands of Stagg Field at the University of Chicago on December 2, 1942.

Dresden, which was under construction three years—and completed within the original schedule—will be one of the prime sources of information on the operation of large nuclear electric plants for the next four years, as it will hold the distinction of being the nation's largest operating nuclear power reactor for at least that long.



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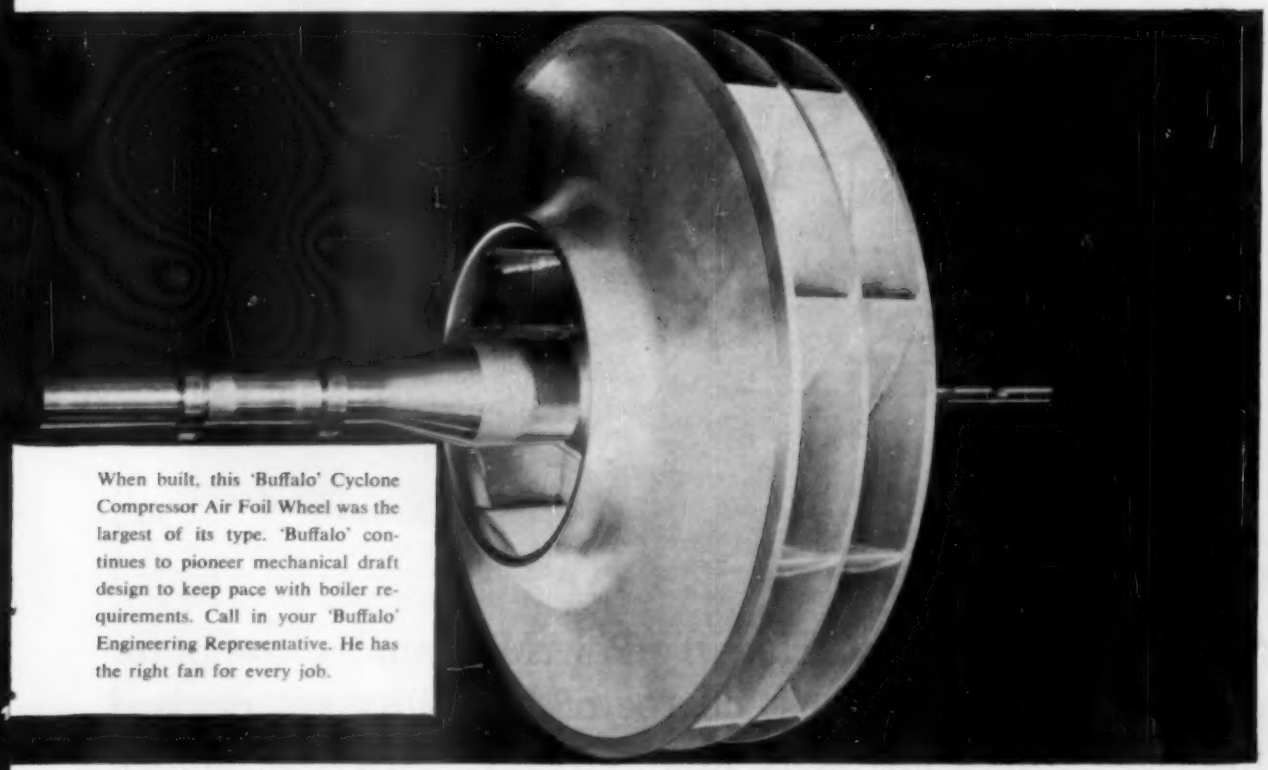

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Plant Design Considerations Utilizing Largest U. S. Raw-Lignite-Fired Boiler

By T. Y. MULLEN*

Burns and Roe, Inc.

Fig. 1—Most recent generating capacity at the Hoot Lake Station, Otter Tail Power Co., features raw lignite brought in by railroad to double track hoppers, a car shaker, a crusher tower for eventual pulverized firing

HISTORICAL records of the city of Fergus Falls, Minnesota, describe an early hydraulic turbine which in the year 1882 drove a pulley system, to serve local industry. In approximately 1902, additions to the turbine system made it possible for the turbine to generate electric power sufficient for "200 lamps," in addition to driving the pulley system. From this early beginning, the Otter Tail Power Company has grown to the point where it has just completed installation of the largest raw-lignite-burning boiler in the United States; to supply steam for a 53.5 mw turbine-generator installed in the newest extension to its Hoot Lake Station in Fergus Falls.

Estimates prepared by the U. S. Bureau of Mines at Grand Forks, North Dakota (1),† indicate that lignite constitutes about 24 per cent of the remaining U. S. reserves of solid fossil fuel, on a tonnage basis, and about 15 per cent on a Btu basis. The greatest portion of this lignite is in North Dakota. The proximity of this large supply of fuel, combined with a certain economic advantage over the use of coal, makes lignite the natural choice for this unit.

The development of successful industrial lignite-burning equipment dates back to about 1925. In 1926, the first successful pulverized lignite installation was made at the Trinidad station in Texas in four boilers, each generating 185,000 lb of steam per hour. Subsequently, other lignite-burning units were installed at the Comal station also in Texas.

Much of the later development work, covering the firing of North Dakota lignite for industrial purposes, was conducted by the Otter Tail Power Company in various stoker-fired plants. Based on this experience, the first modern pulverized fuel installation was made at their Crookston, Minnesota, station which commenced operation in 1948. As this boiler is located alongside a similar stoker-fired unit, it has been possible for the company to conduct numerous comparative performance tests (2), both independently and in cooperation with the Bureau of Mines and the University of North Dakota.

* Chief Mechanical Engineer.

† Numbers in parentheses refer to similarly numbered items in the References at the close of the article.

Data obtained from these tests provided sufficient background for Otter Tail to plan to install the largest pulverized raw-lignite-fired boiler at the Hoot Lake Station.

The following major components of the new extension of the Hoot Lake Station are of particular interest:

Steam Generating Unit

The new extension has a Combustion Engineering tangentially fired steam generator having a capacity of 400,000 lb per hr at 1500 psig and 1000 F, with a four-hour overload capacity of 420,000 lb per hr. After passing through the high-pressure end of the turbine, most of the steam is subsequently reheated to 1000 F. The selection of this type of unit and the steam conditions was determined in an overall economic study which included consideration of equipment and fuel costs, related operating costs and expected unit loading.

The design of a steam generator for pulverized lignite firing presents certain problems generally associated with the low heating value and high moisture content of the fuel. These problems are in addition to those normally encountered in the design of conventional pulverized coal fired units. However, high ash content, often encountered in lignites found in other parts of the world, is not typical of North Dakota lignite.

The design characteristics of the steam generating unit have been conservatively calculated because of limited operating experience with lignite fuels. The furnace heating surface is approximately 8410 sq ft and the furnace volume is 31,000 cu ft, both of which are generous when compared to a coal-burning unit of similar steaming capacity.

The following proximate fuel analysis was used for design purposes. However, to allow for changes in the source of the lignite, the unit capability is sufficiently flexible to satisfactorily burn fuel with a moisture content as high as 42 per cent and a heating value, as fired, as low as 6500 Btu per lb.

Moisture, per cent	36.97
Volatile Matter, per cent	27.90
Fixed Carbon, per cent	29.00
Ash, per cent	6.13
Total, per cent	100.00
Btu/lb (as fired)	6900
Sulfur, per cent	0.72

Naturally pulverizing capacity and draft-producing equipment are also larger than would be furnished for a bituminous-coal-fired unit of comparable capacity. Four, bowl-type pulverizers with integral exhausters are provided, each driven by a 300-hp motor. The nominal capacity of each pulverizer is 32,700 lb per hr, based on fuel with a grindability of 50 Hardgrove, pulverized to a fineness of 70 per cent through a 200-mesh screen. The normal steaming capacity of the boiler can be maintained with three pulverizers in service. The fuel is normally supplied to 16 tilting tangential burners. Provision was made to add gas-burning nozzles to the lignite burners at a future date, should this fuel be available at prices competitive with lignite or if lignite becomes unavailable. One forced and one induced fan are provided with capacities of 167,000 and 262,000 cfm, respectively. Because of the large mass flow through the boiler, both superheater and reheater surfaces are smaller than those for a comparable coal-fired unit. On the other hand, the dust collector and air heater are larger, to accommodate the large gas flow leaving the boiler.

The peculiar characteristics of fine lignite ash have been discussed elsewhere (2). One of the most undesirable of these is the tendency for the ash to build up, causing serious operating difficulties in the most unexpected places. This tendency becomes aggravated as the flue gas temperature approaches the dew point. Because of its physical location at the outlet of the air heater, the dust collector is particularly vulnerable to this buildup. Horizontal surfaces have therefore been eliminated in so far as possible in all parts of the unit, and the lanes between the superheater elements are widely spaced to prevent bridging.

Other features incorporated in the design of the unit to minimize difficulties are (*a*) sectionalizing the dust collector by providing dampers to maintain high gas velocity at low loads through this unit; (*b*) evaluating dust collector tube size to compromise between high collecting efficiency and operating continuity; (*c*) providing electrically operated hammers between the dust collector tube lanes; (*d*) providing cold air bypass ducts and dampers to partially bypass the air heater at low loads, in order to maintain flue gas temperature above the dew point.

The latter precaution was incorporated in the design of a previous Otter Tail unit, in order to maintain the gas temperature at a minimum of 350 F. Several years of successful operating experience showed the added investment to be fully justified. After considerable study, 9-in. diam tubes were selected for this dust collector. This decision was based primarily on previous operating experience with this size tube on smaller lignite-fired boilers. The decision to use hammers, to prevent buildup which would lead to eventual plugging of the dust collector tubes, was made after considering air and steam soot blowers, suspended chains and various other solutions, all of which were rejected for a variety of reasons. The hammers operate relatively slowly and are energized from the control room when the draft loss across the dust collector exceeds a predetermined maximum.

A steam air preheater is furnished to guard against low-temperature corrosion of the Ljungstrom regenerative air heater. The requirement for this becomes apparent when it is realized that winter temperatures in Fergus Falls are sometimes as low as minus 40 F.

Lignite Handling System

Run-of-mine lignite is delivered to the plant by railroad from the North Dakota lignite mines. Even during weather conditions, which have occurred on numerous occasions during the past years, car deliveries have been remarkably free from interruption. In spite of this, a storage area sufficient for about 40 days' supply is provided. While space is available for fuel storage expansion, it is contemplated that this supply will be sufficient to guard against possible interruptions due to weather or other delivery difficulties. The storage area is also intended to provide stockpiling capacity when the plant is operating under low load conditions.

Some problems are associated with the handling of lignite which are not normally encountered when handling coal. Most of these originate with the high moisture content of lignite, and have been a frequent source of

operating difficulty in the past. As a result of work undertaken by Otter Tail engineers and the industry in general, the difficulties in handling lignite are now no more severe than those encountered in handling coal under similar conditions. The principal developments include the spraying of the lignite at the mine with about 1 gal of light fuel oil per ton during cold weather to minimize freezing in the cars, and the provision of snub, bend, take-up, and tail pulleys of open radial slatted construction to assist in the breakup of the accumulation of fines on the belt. On one earlier installation such buildup resulted in improper tracking of the belts on the return idlers, causing belt damage through contact with the conveyer supporting steel. A most recent modification is the provision of doughnut return idlers which will further reduce the buildup of fines. It is interesting to note that oil spraying of the lignite has eliminated the necessity for a thawing pit at Hoot Lake in spite of the extreme Minnesota weather. Apart from the above, no other special handling of the lignite is required prior to its delivery to the pulverizers.

Considerable thought was given to the selection of belt material. Consideration was given to the possible effects of cold-weather operating conditions on shutdown of the heating system, and of the residual oil on the lignite resulting from the oil spraying at the mine. It was originally thought that some compromise would be necessary in view of the fact that a belt material most resistant to oil is not necessarily the most suitable for cold-weather operation. In addition, oil-resistant belt material is generally more expensive. Investigation of other Otter Tail installations indicated, however, that the small amount of oil on the lignite had no adverse effect on belts constructed of high-quality natural rubber. Therefore, this material was selected for the new installation. Although the conveyer galleries are heated, creep drives are provided to keep the belts in motion, if necessary, to prevent freezing. Based on Otter Tail's experience and the low sulfur content of the lignite, no stainless cladding of the chute material was considered necessary.

Double track hoppers are provided together with a car shaker for fast cold-weather unloading of the lignite cars. The track hopper also functions as a reclaiming hopper from the stockpile. From the track hopper, the lignite is conveyed to a crusher tower, which is also used for stocking-out purposes, and then to the bunker. The bunker capacity is 2500 tons, or about two days' supply.

The capacity of the conveyer and crusher system is 300 tons per hr. The entire system capacity can ultimately be extended to 450 tons per hr to accommodate a future generating unit.

Ash Handling System

In addition to the problems encountered in handling and burning lignite, there are certain other difficulties associated with the disposal of the lignite ash. Minnesota's cold winters make hydraulic ash handling methods undesirable. Also, such problems as the effect of sluice water runoff on fish and wildlife must be considered Therefore, it appeared that a pneumatic handling system would probably be more desirable in this instance, even though pneumatic handling of lignite ash has not always been entirely satisfactory in the past.

Certain types of lignite ash have a low specific weight which inherently reduces the conveying capacity of pneumatic systems. In addition, the extreme fineness of the lignite fly ash and consequent low mass often make centrifugal separators ineffective, thus overloading the airwasher which, in turn, leads to a contaminated air discharge. Additionally, the operation of all pneumatic systems can be adversely affected if the ash from the furnace bottom is either semifluid or partially incandescent.

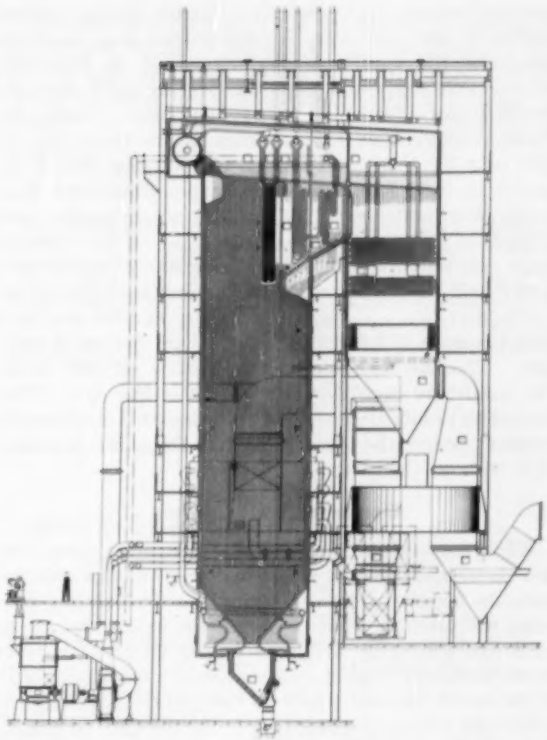

Fig. 2—Sectional drawing of 400,000 lb per hr, 1500 psi, 1000 F tangentially fired steam generator

After evaluation of all these factors, it was decided that none would be particularly troublesome and a pneumatic system would provide the most satisfactory installation. The distribution of ash within the boiler is expected to be as follows:

	Per Cent
Ash Hopper	20
Economizer Hoppers	8
Air Heater Hoppers	4
Dust Collector Hoppers	58
Stack Hopper	10

The capacity of the system was optimized at 20 tons/hr based on the handling of ash from the furnace hopper once and the dust hoppers twice, during each 24-hr period. Ash from the dust hoppers will be handled automatically from the control room during the day and night shifts, without manual attention. Bottom ash will be handled under manual supervision during the day shift only.

Turbine Generator

Because this unit will operate in an area where se-

condary hydoelectric power is available during several months of the year, very careful studies were made to determine the load factor which would be expected. An economic study was prepared covering eight alternate combinations of turbine types and steam conditions. These combinations ranged from steam conditions of 1250 psig 950 F without reheat, to 1800 psig 1000 F reheated to 1000 F. The turbine types considered were double-flow units with 16.5-in. last-stage blades and single-flow units with 23-in. blades. From this study, a single case unit operating at 1450 psig 1000 F/1000 F was determined to be the most suitable for this application.

The unit has a nameplate capacity of 53.5 mw at a back pressure of 1.5 in. Hga and 30 psi hydrogen pressure. The throttle flow at this load is 400,000 lb/hr. The maximum capability of the unit is 58.8 mw. Five extraction points are provided. Because of its extremely compact design, the overall length of the unit is less than 44 ft without the exciter.

Circulating Water System

While the new unit is an extension to a plant containing two small hydroelectric units, and one 7500-kw thermal unit, the supply of water for condenser circulating purposes will often be limited. Both the hydro and steam units are served by a bypass to the Otter Tail River which leads to a pond at an elevation of approximately 70 ft above the basement floor of the plant. As this pond is also the source of water supply for the City of Fergus Falls, the necessity to maintain stable level conditions in the pond to assure proper operation of the city filtration plant is critical. One of the design conditions for the circulating water system was that the pond level should not vary more that 1 ft.

Records kept by the Otter Tail Power Company over the last 46 yr indicate that, on an average, water will be available from this source for condenser circulating purposes for about 73 per cent of the year. A comprehensive study indicated that, for maximum economy, a cooling tower with a capacity of 30,000 gpm was most suitable to supply the remaining 27 per cent of the circulating water requirements. This study also determined that a 30,000-sq-ft, two-pass condenser was required.

The design of the circulating water system incorporated a connection to the 7500-kw unit circulating system, in order that the new cooling tower could be utilized on this unit at periods of low river flows. The layout of the system was planned to effect change-over from the normal water supply to the cooling tower as simply as possible, without water hammer and, without excessive loss of chemicals from the cooling tower system. This is achieved by the use of a single 36-in., 3-way butterfly valve operated remotely from the control room. The operating cycle of this valve takes 40 sec from one extreme position to the other.

Because the water supply to the hydro and steam units is provided through a common 8-ft square cross-section concrete tunnel, a further investigation was made of the potential surge which could be expected in this tunnel on the sudden simultaneous loss of load of both hydro units. It was planned to utilize the screen chamber for the new unit as a surge chamber. To avoid having to design this chamber with abnormal surge capacity, a close estimate of the anticipated surge was required. The studies indicated that a surge could be expected which would peak about 121 sec after shutdown of the hydro units. The study also indicated that a screen chamber of normal proportions would be adequate to protect the system against any anticipated surge. As will be realized, the surge capacity of the new screen chamber actually reduces the surge characteristics of the existing circulating water system.

Condensate and Boiler Feed System

The design of the condensate and boiler feed system is based on a conventional five-heater arrangement consisting of two low-pressure and two high-pressure closed heaters with a deaerating heater and boiler feed pumps located between the high- and low-pressure units. Two full-capacity boiler feed pumps, with hydraulic couplings, are provided.

Makeup to the condensate system is provided by a demineralizing system consisting of one cation and one anion unit followed by a mixed-bed unit. When using a raw water supply originating from the Otter Tail River, a degassifier will not be required. However, space has been provided in the overall design for the installation of this unit should the demineralizing system be required to operate on well water in the future.

Instrumentation and Control Room

In accordance with modern practice, the boiler, turbine, fly ash handling and electrical control boards are located in an air-conditioned, centralized control room on the turbine operating floor. It is planned that this room will be extended as necessary for a subsequent unit. Particular attention has been paid to the lighting and interior finish of this room in order to provide the most effective conditions for the plant operators. Thermopane windows are provided for sound and heat insulation.

Electrical System

The electric generator has a rating of 64 mva at a generating voltage of 13.8 kv. The voltage is stepped up to 115 kv and connected to the Otter Tail transmission system through a 60-mva main power transformer. A 3.75/4.68-mva auxiliary power transformer and interconnecting 3000-amp isolated phase bus duct are provided.

Eleven auxiliary motors larger than 125 hp and a 480-v, 1000-kva unit substation are supplied from a 2400-v system controlled by metal-clad, drawout switchgear. The substation feeds motors between 100 and 125 hp directly while motors below 100 hp are fed through six 440-v motor control centers located throughout the plant area.

A 3.75/4.68-mva transformer is connected to the existing 13.8-kv for startup service.

In addition to the startup circuit, emergency ties at 440-v and 120-v ac and 125-v dc are provided between the existing and new units.

A 704-amp hr, 125-v, d-c storage battery provides power for plant instrumentation and control. Battery charging and float service is provided by a 10-kw diverter pole motor motor-generator set.

Building Design

The building substructure consists of a poured concrete monolithic foundation mat. Piling was not re-

quired. Due to the close proximity to the tailrace of the hydro units, very definite consideration was given during the design period to the safety of the riverbank during construction. It was concluded, however, that there would be no danger of the bank collapsing and the worst that could be expected would be some slight water seepage.

This proved to be the case and the seepage was controlled without difficulty by the use of well points.

The main building enclosure is constructed of aluminum V-beam insulated siding, except in the boiler area where the rear boiler casing serves as the outside wall of the plant. Uninsulated aluminum siding is also used for the walls of the lignite conveyer galleries.

Full use was made of color dynamics for the interior painting schedule of the plant. Careful choice of color and reflectance values for the paint, together with adequate lighting, provide a pleasing plant interior and should aid in improved operating and maintenance efficiency.

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(1) Information Circular 7692—"Technology of Lignite Coals—Part 2," U. S. Department of the Interior, Bureau of Mines, Grand Forks, N. Dak., July 1954.

(2) Cowles, H. R., Chief Engineer, Otter Tail Power Company, Fergus Falls, Minn., "Design and Operational Aspects Regarding Utilization of North Dakota Lignite in Steam Generating Units," American Society of Mechanical Engineers, Fall Meeting, Milwaukee, Wis., September 1954.

AEC Gives Quarterly Civilian Reactor Costs

The Atomic Energy Commission announced in mid-June the results of its fourth successive quarterly survey of costs for civilian nuclear reactor projects currently under active design or construction for installation in the United States. The survey showed that costs of over $51 million were incurred during three months ended March 31, 1960.

The quarterly survey of costs for civilian nuclear power projects from which these amounts are compiled is based on a regular reporting system established in the spring of 1959 with the cooperation of reactor builders. The industry amounts presented in this report are those reported by the industry. Not included in the Commission's quarterly survey are costs for critical experiments, small civilian training reactors shipped fully assembled by the manufacturer, reactors built for export, and general research and development not directed toward specific reactors.

Total costs incurred for the 12 month period were $202.3 million. These figures include costs for plant and equipment, fuel fabrication, research and development (if allocable to specific projects), and land.

TABLE I.—COSTS INCURRED BY QUARTERS FOR U. S. CIVILIAN REACTOR PROJECTS UNDER CONSTRUCTION OR DESIGN

(In Thousands of Dollars)

	Calendar Quarter Ended				
	6/30/59	9/30/59	12/31/59	3/31/60	Total
Electric power prototypes and experiments*					
AEC	13,096	12,203	15,657	17,302	58,258
Electric utilities	23,215	24,541	35,347	26,965	110,455
Total	36,311	36,774	51,391	44,267	168,713
Propulsion plant, N. S. *Savannah*					
AEC	3,571	1,201	2,012	1,096	7,878
Research and test reactors					
AEC	6,111	3,855	4,966	4,367	19,299
Other govt. agencies	492	549	332	215	1,588
Mfrs. & universities	684	1,228	1,605	1,314	4,831
Total	7,287	5,632	6,903	5,896	25,718
All projects					
AEC	22,778	17,259	22,635	22,738	85,410
Other govt. agencies	492	549	332	215	1,588
Electric utilities	23,215	24,541	35,734	26,965	110,455
Mfrs. & universities	684	1,228	1,605	1,314	4,831
Total	47,169	43,577	60,306	51,232	202,284
Research and development					
AEC	6,734	7,686	7,516	7,614	29,550
Electric utilities	2,011	1,177	2,096	1,603	6,887
Subtotal	8,745	8,863	9,612	9,217	36,437
Plant and equipment, fuel fabrication and land					
AEC	6,362	4,517	8,141	9,688	28,708
Electric utilities	21,204	23,364	33,638	25,362	103,568
Subtotal	27,566	27,881	41,779	35,050	132,276
Total (as above)	36,311	36,744	51,391	44,267	168,718

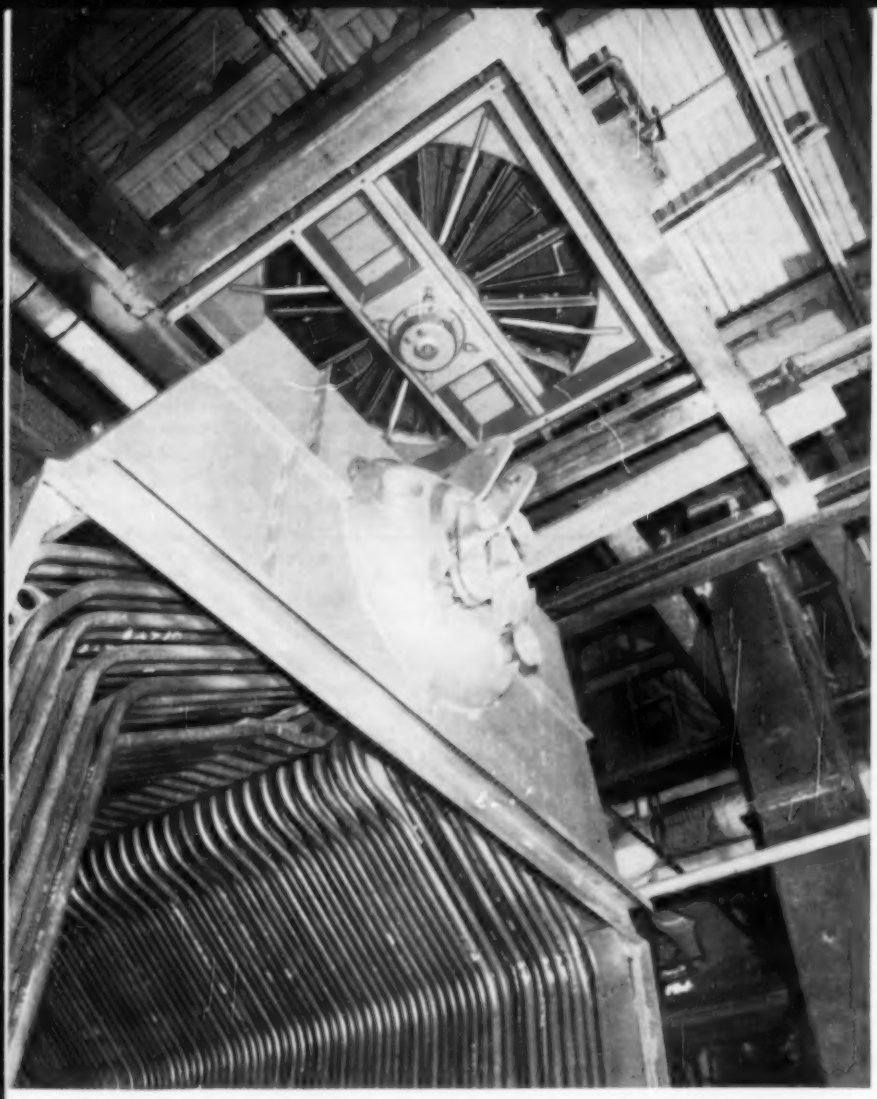
* Breakdown of costs for electric power prototypes and experiments.

TABLE II—TOTAL ESTIMATED COST AND COSTS INCURRED FOR U. S. CIVILIAN REACTOR PROJECTS UNDER CONSTRUCTION OR DESIGN AS OF MARCH 31, 1960

(In Thousands of Dollars)

	Total Cost of Projects	Spent Thru 3/31/60	Remaining to Be Spent
Electric power prototypes and experiments:*			
AEC	281,222	106,910	174,312
Electric utilities	502,180	232,841	269,339
Total	783,402	339,751	443,651
Propulsion plant, N. S. *Savannah*			
AEC	29,000	15,966	13,034
Research and test reactors			
AEC	73,839	35,036	38,803
Other govt. agencies	14,469	12,383	2,266
Mfrs. & universities	27,757	18,023	9,734
Total	116,245	65,442	50,803
All projects			
AEC	384,061	157,912	226,149
Other govt. agencies	14,649	12,383	2,266
Electric utilities	502,180	232,841	269,339
Mfrs. & unversities	27,757	18,023	9,734
Total	928,647	421,159	507,488
Research and development			
AEC	137,497	69,152	68,345
Electric utilities	61,749	39,436	22,313
Subtotal	199,246	108,588	90,658
Plant and equipment, fuel fabrication and land			
AEC	143,725	37,758	105,967
Electric utilities	440,431	193,405	247,026
Subtotal	584,156	231,163	452,993
Total (as above)	783,402	339,751	443,651

* Breakdown of Expenditures for electric power prototpyes and experiments.



The Ljungstrom Air Preheater at the B. F. Goodrich Company Shelton Plant is installed directly over the 65,000 lb/hr Wickes boiler. Flue gas leaving the boiler at 615°F passes through the circular rotor, which absorbs the heat and releases it into the incoming air. Preheated combustion air improves combustion, makes fuel burn cleanly. This Package Air Preheater was factory-assembled, and requird only 100 manhours to install.

At B. F. Goodrich Co.'s Shelton Plant

Air Preheater boosts combustion air temperature 345°F... gives 6% more thermal efficiency

"Only a Ljungstrom® Air Preheater, with its continuous regenerative principle, could meet our requirements", says A. G. Sandomirsky, Manager of Engineering at the B. F. Goodrich Company, Shelton, Conn., plant. "We produce foam rubber 24 hours a day, five and six days a week. With an Air Preheater we can meet process steam requirements more economically, and an Air Preheater helped us to justify the installation of high efficiency, high pressure equipment for by-product power generation."

Here's why the Shelton plant meets its requirements best with a Ljungstrom Air Preheater:

1. Ljungstrom is the most efficient heat exchanger you can buy. The Ljungstrom rotor revolves continuously through the flue gas and incoming air, thus absorbing heat and releasing it *from the same surface*. Since the heat doesn't have to pass through anything, each inch of rotor surface is as efficient as one foot of a tubular recuperator.

2. Ljungstrom is the most reliable heat exchanger you can buy. All heat exchange elements pass through the entire air and gas streams. The temperature of the elements in the coolest region – where fresh air enters – is actually an average of the gas and air temperatures, so it's consistently higher than the coolest point in a recuperative heat exchanger. Result: no cold spots, less chance of moisture formation.

3. Ljungstrom is easiest to maintain. You can inspect it – and clean it–while it's running. Heat exchange elements are divided into modular baskets that can be replaced individually without disturbing the other elements. You can even reverse the elements if the surface has thinned on one edge, effectively doubling the life of the heat exchange surface.

For more information on the Ljungstrom continuous regenerative principle, or on the Air Preheater that meets your requirements, phone MUrray Hill 2-8250 or write to The Air Preheater Corporation.

THE AIR PREHEATER CORPORATION

60 East 42nd Street, New York 17, N. Y.

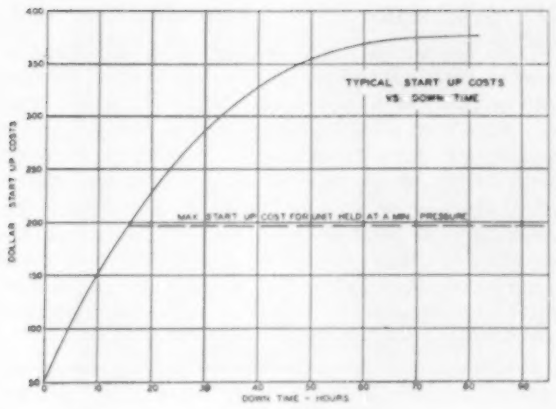


Fig. 1—A review of startup practices should expose operating reductions. A typical startup cost time curve such as above gives general information on the increase in startup costs the longer a boiler has been let cool off

By R. T. DREW

Niagara Mohawk Power Corp.

Economics of Generator Shutdown and Startup*

Until very recently steam turbo-generators, once put on the line, ran quite continuously. The newer ones particularly were shut down only for maintenance or troubles. The procedures used for starting had only to be safe and proper, and the cost involved mattered but little. The addition of considerable steam generation over a period of a few years has changed the picture.

Our system has been shutting down turbo-generators more frequently as time goes on and is now shutting down several of the newer reheat units nightly. This is particularly true during periods of heavy hydro generation. Generation is shut down on these occasions for two reasons: (1) Because it should come off for pure reasons of economy, and (2) to reduce total steam output in order to make use of off-peak hydro generation and to better use low cost energy from other sources.

In our pool operation we often start units for others, or pay others for starts, and therefore need to know costs on a comparable basis. In addition, knowing more about these costs should allow us to improve practices and make savings in a field of increasing importance.

For several years Niagara Mohawk used a standard startup cost for all of its unit type reheat machines. Upon reappraising the practices there appeared to be a need for improvements in procedure and changes in cost evaluation to more truly represent actual out-of-pocket expenses.

Our plants were asked to give us startup cost figures on their units and it was found that practices, and thus costs, were not as uniform as had been assumed. Plants for various reasons operated differently and you may find that in your own systems practices differ more than you think. No criticism of our plants is intended but, as plants are built, the methods of operation develop and, we hope, advance although sometimes in different directions and sometimes practices evolved in older plants are continued in the new.

Our lack of identical practices may be due to a combination of wide geographic separation, differing plant age, and a history of operating administratively as three divisions. These conditions too may be true of some of your organizations.

To set up startup costs for each plant would have been very cumbersome for us to administer. In addition it was felt that some practices were better or more economical than others and should be adopted when possible.

This matter has been discussed with the Steam Plant group and they are in the process of reviewing some of their procedures. Many of these cannot be changed casually because plant conditions and types of equipment differ. It is preferable to have the plant people try out and work toward the new procedures, and so far there has been reasonable success.

The factors affecting startup cost can be put in these three categories: (1) Methods of Banking, (2) Methods of Firing, (3) Turbine Startup Procedures.

Establish Prime Factors...

(1) Methods of Banking

We have four plants with unit type turbo-generators of 100 Mw size and about the same temperature and pressure, in addition to the newest 200 Mw units.

One plant, when a unit is taken off the line, "bottles" the boiler up until it is needed again. Another maintains pressure at 400 lb by intermittent firing. Another maintains pressure at 600 lb. A fourth plant, with 1250 lb pressure, maintained 800–1200 lb while banked,

* Presented at the AIEE Summer General Meeting, Atlantic City, N. J., June 19–24, 1960, as paper No. CP 60-894 and printed by permission of the AIEE.

if the boiler is to remain on so-called 2-hr standby.

These practices affect startup costs, depending on how long the unit has been off, and operating costs when boilers are banked.

It is best, if possible, to get to the point where no firing is done while banked except as required when on standby. A plant which often has a unit on 2-hr standby found by temperature tests that they were just as well off to lower the banked pressure range to 400–800 lb.

(2) Methods of Firing

In our area, where oil is much more expensive than coal, the amount of oil used during startup firing should be kept to a reasonable minimum. Oil firing at these times is more stable; and so is often used more than necessary for reasons of safety because it calls for less attention. This practice may vary among individual crews at a station. The more oil—the easier and more costly the startup.

(3) Turbine Startup

Years ago a unit would be started up well ahead of time, so that it would surely be ready for load on time with no fuss and bother on the part of the crew. This may have been necessary when the loss of a unit could have meant dropping of load. These days, when we have larger interconnections, more accurately determined reserves, and are taking units off frequently for reasons of economy, fuel wasted by a long startup should be avoided. Some crews start a unit earlier to avoid rushing and to be prepared for contingencies; also to have unit on line ahead of shift time and so give the operators plenty of time to wash up.

It seems that the better crews working as a team prefer to start in as short a time as is considered proper, and get load on the machine just as soon as it is ready. This also seems to give the best temperature distribution, lessens stresses, and reduces startup costs.

Define Startup Conditions . . .

After obtaining preliminary figures on startup costs we decided that, for purposes of easier administration, startup charges should be set for three conditions:

1. Warm Start. Approximately 10 hr off—an overnight shutdown.
2. Semi-Warm Start. Approximately 30 hr off—off one day, such as a Sunday.
3. Cold Start. Off a full week end or longer.

We are presently obtaining up-to-date costs for startup. The items figured in the starting cost are: (1) Fuel used for firing, (2) kwh for auxiliaries, (3) water cost.

Most of the figures were obtained by checking meter and counter readings on startups as they occurred. This should give the best average of normal startups by a representative group of crews.

For our 100 Mw reheat turbo-generators, typical starting costs are as listed below. They include a 15 per cent allowance for incremental maintenance.

	Warm		Semi-Warm		Cold	
	$	%	$	%	$	%
Oil	56	39	138	44	173	46
Coal	65	45	114	36	130	35
Water	10	7	22	7	28	8
Power @ 3.5 m.	14	9	40	13	44	11
Total	145		314		375	

When a unit is started and put on the line, or taken off the line to be shut down, there is a period of approximately one hour in each instance when little or no energy is produced. For this reason another cost which should be included in startup considerations is 2 hr of no load for each shutdown cycle. This amounts to about $60 for a 100 Mw unit.

Boiler operating costs for such units, when they are kept banked for standby purposes, amount to about $10 per hour. This figure may be less if lower banked pressures are maintained.

Determine Equipment Effects . . .

There are some other factors involved in startup procedures which should be given more attention—from both the cost angle and the equipment stress angle.

(1) Drum Level

This can be down as the boiler cools, maintained at normal level, or the drum may be flooded during some steps in the operation. These methods are recommended by various groups as preferred ways to relieve boiler stress, and have a bearing on cost due to water and make-up.

(2) Winding Temperature Control

Frequent starts may have an effect upon the expected life of winding insulation. There should be a best procedure to follow in controlling temperature at startup, and while at light load. This will depend upon experience, generator design, and manufacturer's recommendations.

(3) Rate of Pickup After Startup or From Light Load

Turbines operating at light loads may require a surprisingly long time to get to full load. This will vary with the length of time run at light load, and may have an effect upon reserve calculations.

Conclusion

Review of startup practices can result in better operation and reduced cost. To be practical for daily use, these costs should be rounded off so that one value will apply to several similar units, Fig. 1. Further the costs so used should be those actually incurred during normal operation.

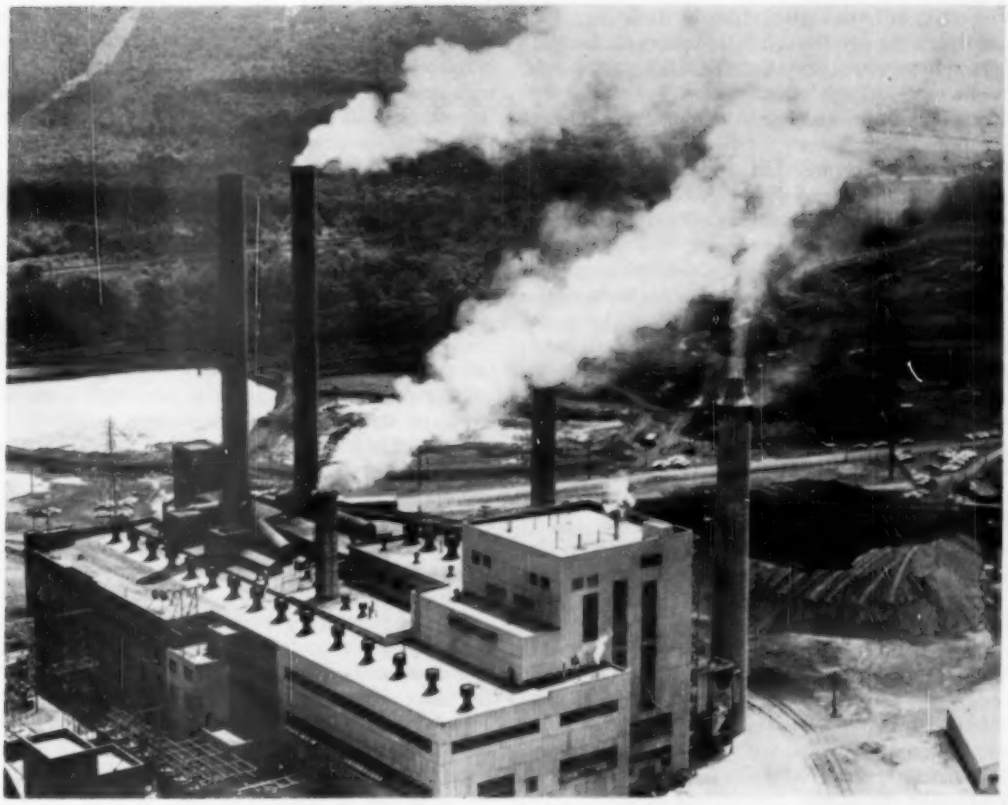


Fig. 1—Cover photo plus the above aerial view demonstrates the effectiveness of the Venturi stack addition in relation to other stacks, some 100 ft higher, and also highlights the problem the plant operators faced

The Invisible Stack

Instead of making a chimney higher, a 10-ton Venturi nozzle of stainless steel, designed and built by Aerotec Industries, was installed on top of the stack at Pennsylvania Electric Company's Seward Generating Station. The stainless steel resists corrosion by the hot gases and the nozzle makes the stack perform as if it were 100 ft higher, stepping up exit velocity of the gas and shooting it up high in the air for fast, effective dissipation.

How do you make a 214-ft chimney perform as efficiently as one of 314 ft without substantially increasing chimney height? No easy task—but one which calls for sound engineering. That's just what engineers of Aerotec Industries, Inc., accomplished recently when they designed and installed a new 10-ton nozzle of nickel stainless steel on a stack at Pennsylvania Electric Company's Seward Generating Station in Johnstown, Pa.

Cantilevered from compression supports atop the concrete chimney, the nozzle—only 16 ft high and set just 2 ft above the chimney (Fig. 2) makes the 214-ft stack perform as effectively as one a hundred feet taller, Fig. 1.

The stack nozzle Venturi design, discharges 485,000 cfm of gas—shooting it 100 ft or more above the chimney top for rapid dissipation. (See cover photo) The nozzle has stepped up the exit velocity of the gas from 30 to 110 fps. Because of a unique flexible seal between stack liner and nozzle, this increase in emission velocity has been achieved with a draft loss of less than 2 in. water gage.

When Penelec decided to improve operations by lengthening the 19 ft O.D. chimney, the obvious solution was to extend the existing structure 100 ft. But inves-

tigation by Gilbert Associates, Inc. of Reading, Pa., determined that although the reinforced concrete foundation could support a 100-ft addition, the taller stack would be more vulnerable in high winds.

This is where Aerotec came into the picture. Called upon to supply the answer, engineers of the Special Products Division of Aerotec Industries (formerly Pratt-Daniel Corporation) came up with a successful nozzle design that would increase the emission velocity from 30 to the desired 110 fps.

To be sure, Aerotec encountered some tough engineering problems along the way. The chimney is lined all the way to the top, and an 8-in. annular gap, which must remain unobstructed for circulation of cooling air, separates the concrete exterior from the brick lining, Fig. 3. Wind can cause the chimney itself to sway as much as 3 to 5 in. while not moving the inner brick lining. Thermal expansion, however, does cause the brick liner to move vertically up to a maximum of 2 in. And the entire job had to be completed during a three-week normal shutdown period.

Despite these difficulties, Aerotec did the job in the required time. The Venturi-shaped nozzle tapers from 16 ft at the bottom, coinciding with the inner diameter of the brick stack liner, to a diameter of only 9 ft 8 in. at the top. Moving through the Venturi nozzle imparts greater dynamic energy to the gas, speeding it up as it exits.

Constructed of Type 316-L stainless steel, the nozzle successfully resists corrosion by the hot stack gases. An extra-low carbon material (max. 0.03 per cent with about 17 per cent chromium, 12 per cent nickel and 2¼ per cent molybdenum, Type 316-L stainless combines the advantages of good corrosion resistance and high strength.

Aerotec engineers selected Type 316-L stainless because high strength and corrosion resistance were of paramount importance. This type stainless successfully withstands the corrosive action of the hot stack gases, which exit at about 240 F.

Moreover, the choice of Type 316-L for the nozzle resulted in a tremendous weight saving, significant since the nozzle must be supported by the chimney. Initially use of a low alloy, high-strength steel had been considered. But by using this steel it would have been necessary to double the plate thickness to ⅜ in. to withstand the corrosive stack gases, and this would have made the nozzle far too heavy.

Erection costs were lower with 316-L stainless because of its higher strength/weight ratio. If the low alloy steel had been used, it would have had to be put up in smaller sections.

Total cost for the nozzle installed was $53,000. Fabrication and installation of the nozzle took close to 22,000 lb of Type 316-L stainless, including the weld wire. Use of the extra-low carbon stainless prevented carbide precipitation in the welds.

Aerotec engineers considered using other types of stainless for the nozzle. However, a study of the relative costs and requirements indicated Type 316-L to be the most economical solution.

Getting an effective seal between the stack liner and the stainless nozzle to prevent reduction in gas velocity was one of the most difficult problems. For one thing, the seal had to withstand the corrosive attack of the hot stack gases. For another, it had to be flexible be-

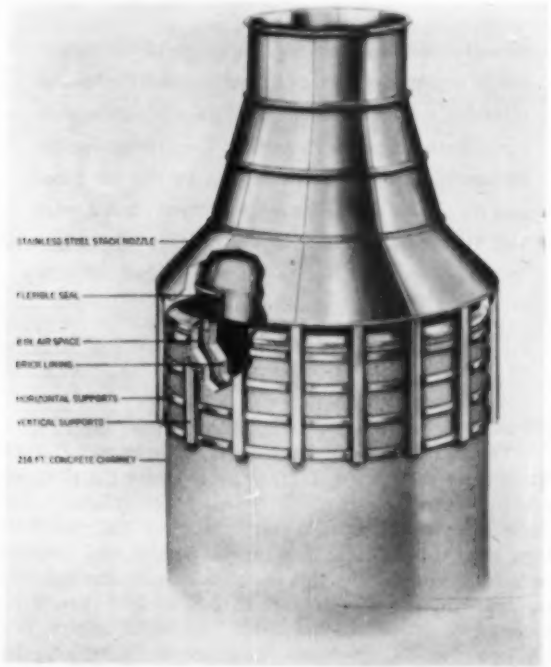


Fig. 2—Wash drawing above carries labels describing the pertinent points of the nickel nozzle serving as a Venturi outlet for a concrete chimney

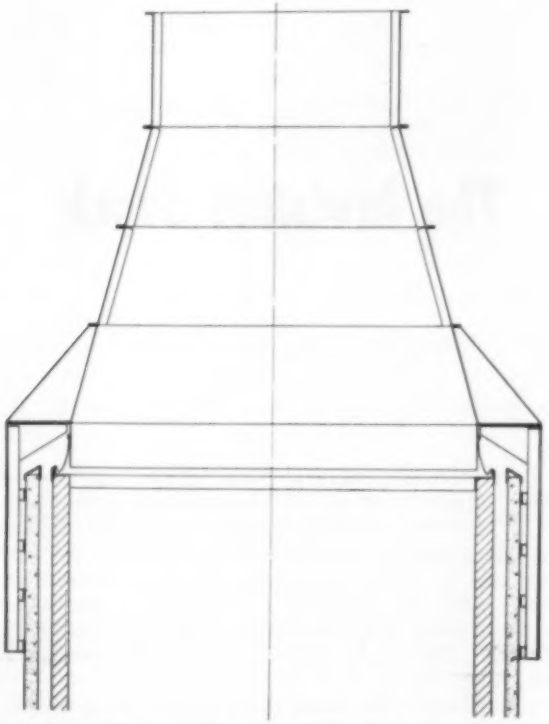


Fig. 3—Details of the special flexible seal between chimney and addition which permitted sharp rise in emission velocity with low draft loss

cause of thermal expansion of the brick liner and wind sway of the concrete exterior. Finally, to minimize draft loss it had to be virtually gastight despite the 3- to 5-in. play.

Aerotec met this problem by using a flexible diaphragm woven from du Pont's Teflon fiber impregnated with the new Viton A synthetic rubber. This tough, pliable material resists tear and rupture, is unaffected by freezing temperature, and can withstand prolonged contact with corrosive gases at 400 F—far higher than actually encountered in the stack nozzle.

The woven Teflon sheet impregnated with Viton A is 0.020-in. thick, and comes in a 31-in. width. It costs $60 per lineal yd.

The flexible seal on the nozzle was fabricated with grommets or eyelets for fastening. The grommets are on 6-in. centers.

A new cap of 316-L stainless plate $^3/_8$-in. thick replaced the old cast iron cap on top of the brick liner. The new cap has a special clamping and bolting bar around it to hold the flexible seal. There is a similar bolting bar or band on the light gauge stainless skirt above.

The flexible sheet was squeezed through the bars on the cap and skirt, doubled over, and bolted through the grommets. Elasticity of the sheet eliminated the possibility of damage from lateral tear stresses. Slack was provided to reduce stress transmission between liner and nozzle.

The stack nozzle, its weight sprung by cantilevering, is thus supported by the concrete exterior of the chimney, with a flexible seal all around between brick liner and nozzle, Fig. 2.

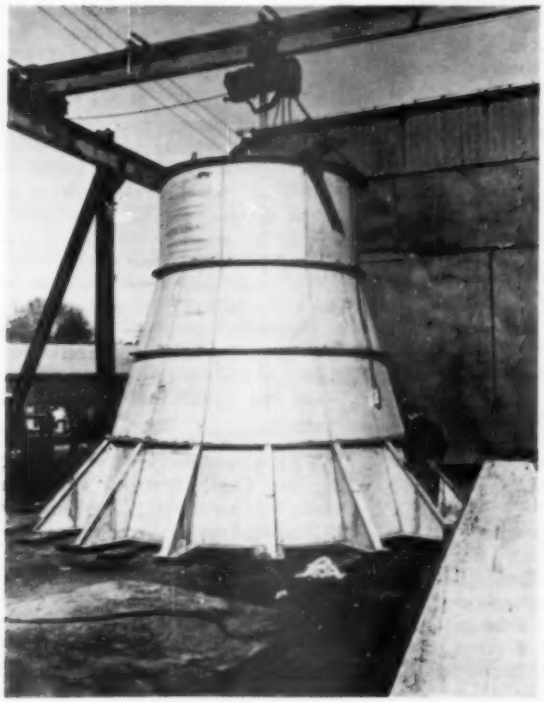


Fig. 4—Each nozzle section was made in a jig, no single piece weighing over 500 lb, so reassembly went smoothly

The pressure drop caused by the nozzle itself is equivalent to only 1.9 in. water gage of draft loss. However, during the modernization of the unit a mechanical dust collector of the multi-tube cyclone type was installed ahead of the electrostatic precipitator to knock out almost 80 per cent of the dust, mostly fly ash, before the gas enters the precipitator. The pressure drop through this mechanical collector is 2 to 2.5 in. water gage.

Accordingly, the total draft loss for the entire unit as a result of these changes is between 4 and 5 in. water gage. For compensation, a new rotor and more powerful motor were installed on the induced draft fan to speed it up.

The fan now has a 1250-hp motor. Because of the increased centrifugal force, a heavier-duty wheel was installed on the fan by American Blower. Its $76^1/_2$-in diam equals that of the previous wheel, but it has a heavier center plate and heavier rims. Blades are of steel, and the wheel's hub is of cast nickel-iron alloy. The fan is the double inlet type but is only two-thirds of double width. Speed has been stepped up from 580 to 705 rpm.

The nozzle was fabricated of Type 316-L stainless in eight sections with intermediate stiffeners. All vertical stiffeners were positioned on the inside to avoid turbulence, and all vertical brackets were covered by plates to prevent swirling.

Each nozzle section was made in a jig: the pieces were all prefitted. The nozzle was assembled and match-marked at Aerotec's plant so that it could be readily reassembled (Fig. 4). It was then dismantled for shipment to the job site.

It took six men, working 10 hr a day, only 12 days to install the new stainless nozzle. The men did not work week-ends, and three days were lost because of bad weather conditions during the three-week shutdown. Wint & Tosh, boiler erectors of Burnham, Pa., handled the installation, with field supervision by Aerotec engineers.

The nozzle is cantilevered from vertical members fastened to four compression bands around the outside of the stack. These four bands, all of Type 316-L stainless, were cinched up tight around the chimney, bolted with a single bolt for each joint, and then welded. The nozzle rests on 16 horizontal plates supported by vertical brackets. The brackets are held by pairs of angles bolted to lugs on the compression bands and then welded.

Hardest part of the construction was adjusting all the brackets so that the horizontal plates would be level. This was done by shifting the circular compression bands up and down until the tops of the brackets were level.

While the nozzle is of welded construction, many Type 316-L bolts were used during erection. A few of the lighter top sections of the nozzle were bolted together on the ground and seal welded before being lifted to the chimney top. Other heavier sections were bolted together atop the stack, then welded. The heaviest single piece lifted weighed 500 lb.

Since the nozzle itself is only $^3/_{16}$-in. thick, the flanges holding its sections together function as stiffeners as well as bolting connections.

The selection of Type 316-L stainless for its corrosion resistance and high strength was essential for the successful design and operation of this stack nozzle. Despite the close timing on this job, no major difficulties were encountered in shop fabrication and field erection.

Abstracts From the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

Change of Rank, Rank Criteria and Classification of Coals on the Basis of Vitrain Analyses. Pt. I and II. K. Patteisky and M. Teichmüler *Brennst-Chemie* 1960, **41** (Mar.), 79–84 (Apr.), 97–104 (in German).

It is known that the change of rank of vitrain is not a straight but a broken line, the most important break occurring at 87 per cent C and 29 per cent VM. With these changes of rank the usefulness of rank criteria varies and the best criteria for various ranges or rank are discussed. The analysis diagrams are evaluated for a coal classification on vitrain basis. The boundaries of the large rank stages, especially between the various types of brown coal and between brown and bituminous coal for which previously no quantitative data were available, have been demarcated.

The Removal of Chlorides from Coal by Leaching: II. Weathering in Stockpiles. E. W. F. Gillham. *J. Inst. Fuel* 1960, **33** (Apr.), 193–8.

In follow-up studies washed and unwashed coal of high chlorine content was exposed to normal weathering conditions in stockpiles. After three years the chlorine content of the washed coal had fallen from 1 to 0.3 per cent. Unwashed coal takes a considerably longer time to achieve similar results.

Physical and Economic Problems in the Transport of Solid Particles in Liquids and Gases. W. Barth. *Chem. Ing. Tech.* 1960. **32** (Mar.), 164–71 (in German).

After outlining the problems encountered in pneumatic and hydraulic transport of solid materials an attempt is made at defining the conditions in which this type of transport is economical.

The Handling of Solid Fuels and the Removal of Ash in Private Power Stations. E. Dordain. *Tech. Mod.* 1960, **53** (Feb.), 46–58 (in French).

The various types of equipment used in France for moving solid fuels such as conveyors, elevators, cranes and hydraulic and mechanical ash removal installations are described.

Coal Handling Plants in Steam Power Stations. W. Fraass. *Elektwirtsch.* 1960, **59** (Mar. 20), 148–52 (in German).

The boilers at the Schwandorf power station are fired by brown coal which arrives in special wagons and is discharged into two bunkers of a total capacity of 10,000 tons. From these the coal is transported by a series of belt conveyors to the storage area or the boiler house bunkers. The various installations and their controls are briefly described.

Dust Control at Milliken Station. W. R. Wise. COMBUSTION 1960, **31** (Mar.), 39–40.

Spraying of dust with a solution containing a wetting agent is carried out at the car dumper, discharge from the pan feeders to the stocking out conveyor, discharge from vibrating feeders to the reclaiming belts and from the crushers to the boiler house conveyors.

Steam Generation and Power Production

Determination of Stresses in Pressure Vessels. H. Jung. *Chem. Ing. Tech.* 1960, **32** (Mar.), 217–22 (in German).

A simplified theory of a shell resistant to bending forces has been developed and solutions are presented for the cylinder, sphere and cone. The equations are tabulated. A calculated example shows good agreement between theoretical and experimental results.

Flow of Fluids. M. Murray. *Ind. Engng. Chem.* 1960, **52** (Mar.), 257–61.

The annual review of literature published in 1959.

The Effect of Temperature Drop Between Components of a Boiler Drum and the Stresses Set Up in It. Yu. A. Magnitskii. *Teploenergetika* 1960, **7** (Mar.), 48–51 (in Russian).

Methods are suggested for considerably reducing the drum stresses by means of a change of water level during start-up and shutdown.

C.E.G.B. abstract

Features of the Operation of the 67-4-SP Once-Through Boiler on High-Ash-Content Fuel. A. L. Bychkovskii. *Energomashinostroenie* 1960 (Feb.), 21–5 (in Russian).

A brief description is given of the basic features of operation of the 67-4-SP once-through boiler when high-ash-content fuel is used, with particular reference to stability of furnace operation, optimum firing conditions, thermal conditions of the heating surfaces and boiler economics.

C.E.G.B. abstract

Shot Cleaning of Convection Heat-exchange Surfaces. D. Humphrey. *J. Inst. Fuel* 1960, **33** (Apr.), 173–9.

The design and installation of shot cleaning equipment is described and the advantages of this technique, especially the cleaning during full load conditions, set out.

Liquid and Gaseous Fuel Firing

The Use of Heterocyclic Tertiary Amines for the Control of Corrosion caused by Flue Gases. E. Brett Davies and B. J. Alexander. *J. Inst. Fuel* 1960, **33** (Apr.), 163–73.

The theoretical basis for the use of tertiary amines as corrosion inhibitor in oil-fired boilers is explained and experimental and field experiences described. It was found that the injection into the flue gases of 0.03 per cent of these amines by weight of the rated fuel capacity afforded protection of economizers, air heaters and ancillary equipment, but that difficulties may arise in their uniform distribution in the flue gases. Deposits on air heaters can be removed by water washing as also any accumulations of carbon deposits.

Furnaces and Combustion

General Combustion Nomogram for the Assessment of Flue Gases and their Calculations by Means of Fuel Coefficients. H. Viereckl. *Energie* 1960, **12** (Mar.), 89–95 (in German).

A simple nomogram has been constructed for flue gas compositions and excess air determinations. The nomogram enables to rapidly assess the quality of the combustion from the fuel or flue gas analysis. The calculation of the various coefficients from the fuel or flue gas analysis is given in a first table and average values are given in a second table and graph. A further table gives the equations for the calculation of the gas and air volumes and their weights. An example shows the application of the nomogram.

The Release of Sodium Aerosols During the Combustion of Pulverized Coal: a Laboratory Investigation. D. Ounsted and J. Schoen. *J. Inst. Fuel* 1960, **33** (Apr.), 199–206.

The furnace for firing 100 gr of pulverized coal per hour and its equipment are described. The effect of ash content of the fuel and its particle size on the formation of sodium aerosols has been studied; this increases with increasing particle size and decreasing ash content. Suggestions

are made to reduce deposit formation caused by sodium aerosols by burning coal of high ash content, reinjection of fly ash or finer grinding of coal.

Water-Side Corrosion and Water Treatment

"Ultra-Pure" Boiler Feedwater. D. N. Hill. *Heat Engng.* 1960, **35** (Jan./Feb.), 104–6.

Tests carried out by the TVA at the Johnsonville power station's No. 9 and 10 units have shown that suitable designed evaporators are able to produce consistently feedwater with a vapor purity below 0.1 ppm (0.008–0.071).

Feedwater Treatment for Low-Pressure Boilers. W. F. Gerrard. *Steam Engr.* 1960, **29** (Apr.), 236–40.

One method for internal and one for external treatment are described. The first uses anhydrous trisodium phosphate, anhydrous sodium sulfite, sodium hexametaphosphate, tannin or sodium alginate and anhydrous or crystalline magnesium sulfate. The quantities required and the manner of their application are stated. The second consists in preliminary base exchange, treatment of the water with sulphuric acid to partially convert the sodium bicarbonate to carbonate, forcing the partially neutralized water through a polythene spray to remove part of the CO_2 and then pass the water through a bank filled with granular magnesium oxide to absorb the residual CO_2 and convert any bicarbonate into carbonate. The advantages of the process over lime-soda softening are outlined.

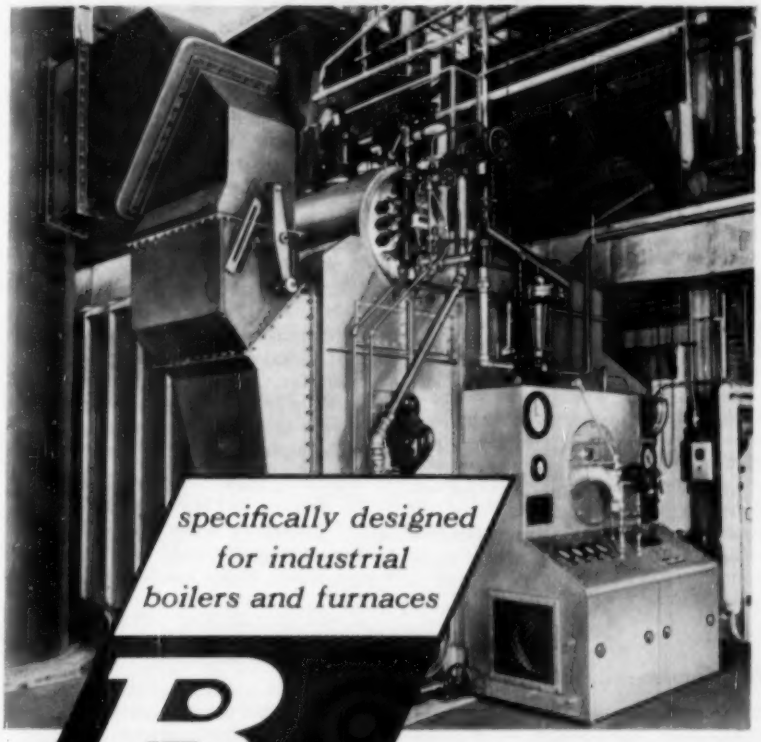
Corrosion in Power Station Feed Systems. A Trial of Cyclohexylamine and Morpholine and their Evaluation as Corrosion Inhibitors. B. Tuck and E. M. Osborn. *Chem. and Ind.* 1960 (Mar. 26), 326–31.

Both cyclohexylamine and morpholine at an amine concentration of 1–2 ppm reduced the iron content of the boiler feedwater from 20 pptm to 5 pptm, but the copper content only from 20 pptm to 10–12 pptm. Morpholine was slightly more effective in controlling metal pickup.

Damage to Boiler Tubes due to Copper Deposits from Boiler Water. A. Splittgerber and F. Börsig. *Maschinenschaden* 1960, **33** (Feb.), 21–4 (in German).

Investigation of the internal deposits of corroded tubes of a 140 atm (gage) boiler revealed, in addition to magnetic iron oxides, considerable quantities of copper which was deposited from the boiler water due to high local thermal stresses of the pff boiler and led, by a catalytic action, to increased oxidation of the tube wall

Combustion Controls



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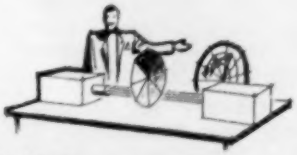

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through decomposition of the steam. The observations made on investigation of this damage agree in nearly all respects with the results obtained in other countries and, recently, in Germany in similar cases.

From *C.E.G.B. Digest* 1960, **12** (Apr. 23), 1040.

Investigations of Impurities in the Cooling Water of the First Nuclear Power Station. P. N. Sljurasev, V. A. Ivanov and L. N. Nesterova. *Kernenergie* 1960, **3** (Mar.), 248–51 (in German).

The investigation concerned the corrosion of steel in the first Russian nuclear power station near Moscow and the rate at which the corrosion products were carried out by the cooling water. The rate of carrying away these products is a function of the flushing of the primary circuit by light water and the reactor output. Irradiation in a light water cooled reactor causes formation of nitric acid by oxidation of the dissolved nitrogen. It could be shown that the water contains ions of Na, Ca, Mn, Ni, Co, Cr and Si, but Fe and Cu are present as colloids.

Flue Gas, Ash and Dust

Testing the Rotary Regenerative Air Preheater. Part I and II. J. Waitkus. COMBUSTION 1960, **31** (Mar.), 30–7 (Apr.), 60–5.

This first part deals only with methods, equipment and procedures for the flue gas analysis. The second part deals with difficulties in measuring flue gas, air and metal temperatures, pressure and draught and the most suitable instruments for each application.

Heat Recovery Plant

Thermal Calculation of Steam-Heated Feed Water Preheaters. H. Kerwat. *Energie* 1960, **12** (Mar.), 98–101 (in German).

The difficulties of determining the heat transfer coefficients in the subcooling, condensation and condensate cooling zones are discussed and values obtained in extensive tests tabulated. An example illustrates the application of these coefficients in the calculation of the area of each of the three zones.

Hydraulic Analogue for Studying Steady-State Heat Exchangers. J. Prochazka, J. Landau and G. Standart. *Brit. Chem. Engrg.* 1960, **5** (Apr.), 242–7.

Hydraulic analogues for counter and mixed flow heat exchangers are presented and the results presented in tables and graphs.

Power Generation and Power Plant

Power Station Heat Cycles. P. J. Cameron. *Elect. Rev.* 1960, **166** (Apr. 8), 675–80.

The heat cycles of conventional and nuclear power stations are compared. The possibility of using reheating in nuclear stations are explored and a particular scheme involving a back-pressure turbine driving a circulator is outlined; the gain in efficiency is discussed.

Conduction and Radiation Losses and Ventilation in a Power Station. M. Sack. *Elektwirtsch.* 1960, **59** (Mar. 20), 142–8 (in German).

Investigations into the conduction and radiation losses in a power station and efforts to improve comfort conditions for the personnel are reported. It is shown that a considerable recovery of the losses can be combined with improved working conditions.

Efficiency Plus. E. R. Knight. *Electricity* 1960, **13** (Mar./Apr.), 76–7.

Spondon H is the first CEGB station specifically built to supply process steam to an industrial consumer (Brit. Celanese Ltd.). When finished it will contain four 180 klb/h stoker fired boilers supplying steam at 900 psi and 875 F to three 10 mw turbogenerators exhausting at 160 psi and 510 F. The thermal efficiency of this station exceeds 60 per cent.

Big Power Comes to Staten Island. M. L. Branin. *Coal Utiliz.* 1960, **14** (Feb.), 14–8.

The first unit of the Arthur Kill No. 2 station consists of a boiler rated at 2400 klb/h at 2100 psi and 1050/1000 F and a 335 nw cross-compound turbogenerator. The boiler has twin furnaces, one containing the reheater and the other the final superheater. Each furnace has 16 burners for coal, oil and gas firing supplied from 8 mills each with a capacity of 38,400 lb/h at 63 Hardgrove and a fineness of 77/200 mesh. Furnace ash is removed by a hydraulic system, fly ash by a vacuum system. The combined multicyclone and precipitators have a separation efficiency of 99 per cent. The furnace operates under positive pressure and there is no i.d. fan, but cold flue gas can be recirculated from the economizer outlet to the furnace bottom. The air is preheated by steam before entering the rotary preheater.

Progress of the Tennessee Valley Authority. Anon. *Engineer* 1960, **209** (Apr. 8), 626–8 (Apr. 15), 666–8 (Apr. 22), 700–4.

The power system of the TVA was increased by 775 mw during 1959 and 66 per cent is now generated in steam and 34 per cent in hydroelectric stations. At the Johnsonville Station three 150 mw units were completed and a fourth nearing completion giving a total capacity of 1275 mw. At Gallatin station a 275 mw unit was commissioned and a second 275 mw unit almost ready bringing the total capacity to 1050 mw. At Widows Creek the first 500 mw unit is to be commissioned in October 1960, consisting of a cross-compound double flow turbine with two 275 mw generators and a controlled circulation boiler rated at 3850 klb/h at 2450 psi and 1053/1003 F with feedwater at 530 F. The calculated heat rate is 8913 Btu/kwh. A further 500 mw unit is to be installed at Colbert station. Future developments are outlined.

The Second (French) Nuclear Power Station. Bienvenu, B. Saitcevsky, F. Bourdillat, C. Tourgeron, R. Millot, Lamiral and L. Laurent. *Nucl. Pwr.* 1960, **5** (Apr.), 118–23.

EDF2 to be in operation in 1962 will have an output of 791 mw (th) and 198 mw (e) using natural uranium in Mg cans, grafite as moderator and CO_2 at 368 psi as coolant with an inlet temperature of 195 C and an outlet temperature of 365 C. There are 4 heat exchangers producing h-p steam at 340 C and 473 psi and l-p steam at 126 psi and 340 C. Two 115/125 mw turbogenerators will be installed. Details of the design are presented.

Kahl Nuclear Power Station. H. Kornbichler. *Engineer* 1960, **209** (Apr. 8), 624–5.

This first German power reactor is rated at 60 mw (th) and 15 mw (e) and is of the boiling water type. Primary steam flow is at the rate of 118.5 t/h at 71.3 at and secondary steam flow at

Editor's Note:

As we point out each month, the materaial for this department is drawn from the International Combustion Ltd. Monthly Technical Bulletin. The Bulletin's editor, K. R. Lenel, advises us of a new publication, "Fuel Abstracts and Current Titles," published by the Institute of Fuel, 18 Devonshire St., Portland Place, London, W.1, which does a very comprehensive job. We have seen it and endorse it for individuals and libraries of universities, consulting engineers, manufacturing organizations. Write to the Institute direct for subscription rates.

105 t/h at 47.8 at. Details are given of the reactor building, turbine hall, office block and water purification plant.

•

Instruments and Controls

The Determination of the Optimum Design Data of the Steam Power Process by Electronic Computers. K. Knizia. *Elektwirtsch.* 1960, **59** (Mar. 20), 137–41 (in German).

The determination of the optimum process efficiency as a function of temperature and pressure of the superheated and reheated steam, enthalpy of the feedwater entering the boiler, number of preheating stages, thermal efficiency of the turbine, increase of enthalpy of feedwater in the pumps and saturation temperature in the condenser can only be effected by a computer. The preparations necessary for its use are described.

Automatic Power Control Improves Precipitator Efficiency. L. L. Little and C. R. Zink. *Pwr. Engng.* 1960, **64** (Mar.), 64.

The improvements in electrostatic precipitator efficiency due to the introduction of automatic control of power input are outlined.

The Behaviour of the Venturi Pneumatic Pyrometer in Industrial Furnaces. R. E. Holland, R. Jackson and G. G. Thurlow. *J. Inst. Fuel* 1960 **33** (Apr.), 180–7.

The application of this pyrometer in open-hearth furnaces, converters, glass tanks, oil and pulverized coal fired boilers is described. The advantages of this type of pyrometer are that it is accurate at all temperatures, has a rapid response, is only slowly blocked by dirty gas and can easily be cleaned.

Metallic Thermocouples for the Measurement of Temperatures above 1600° C. Anon. *Metallurgia* 1960, **61** (Mar.), 141–2.

Thermocouples with iridium-60 per cent iridium-40 per cent thorium are suitable in oxidizing atmospheres up to 2000 C. Irridium-tungsten couples can be used in neutral (argon or helium) atmospheres up to 2300 C. Tungsten-tungsten-rhenium couples in neutral or reducing atmospheres can measure temperatures up to 2800 C.

Cast Iron from Steel Scrap. Anon. *Metallurgia* 1959, **60** (Dec.), 261–2.

Instead of pig iron Ferranti Ltd. will use steel scrap with added recarburising compounds, silicon and manganese in a 3 t capacity electric furnace for the production of non-magnetic and spherical graphite cast iron and a combination of both. Economies and flexibility are the chief advantages of this new process.

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Technical Book Reviews

By John H. Cruise

Any of these may be secured by writing Combustion Publishing Company, 200 Madison Avenue, New York 16, N. Y.

Steam Power Plants

By Chas. Donald Swift

$11.50, 491 pages

This book is divided into 20 chapters ranging from initial design concept to plant acceptance tests.

Subjects covered are design and purchase, combustion plant personnel, safety, operation and maintenance, water treatment, cooling towers, condensers, turbo generators, electrical systems. Instruments and automatic control are also covered.

This book was written by a member of a world-wide engineering and consulting service and his work reflects wide personal experiences.

It would be a handy volume for book case of the smaller consulting services in avoiding many of the pitfalls encountered in the preliminary, construction, training, operating and testing periods.

The sequence from plant inception to acceptance is well done. The book is non-technical and is easily read.

Radiation Pyrometer and the Underlying Principles of Radiant Heat Transfer

By Thomas R. Harrison

$12.00, 234 pages

This text is divided into six chapters ranging from "general principle" to specific cases of "black body" and "non-black body" radiation.

Radiation pyrometers are fully covered and the text ends with a multiple of references, charts and tables.

This text is written for instrument designers but it would also be valuable for classroom work because of the clear and comprehensive explanation of the radiction laws with their mathematical derivations. It would have limited use in applied engineering.

Internal Combustion Engines — Theory and Practice, Vol. I

By Chas. Fayette Taylor

$16.00, 514 pages

This book can be described as the application of thermodynamics to the internal combustion engine in its varied types.

Illustrative examples with accompanying graphs are used throughout the book for clarity.

Engineering Thermo-dynamics

By James B. Jones and George A. Hawkins

$8.50, 724 pages

In addition to the usual basic subjects covered in thermodynamics, the author has included such subjects as "combustion chemical reactions" and chemical equilibrium, vapor and gas power cycles, refrigeration, binary mixtures and heat transfer.

As stated by the authors this text is written as an introduction to the basic principles of engineering thermodynamics and is not confused by application of practical problems. It is well written and is easily understood.

Chemical Process Principles—Part II

By Olif. A. Hougan, Kenneth M. Watson and Roland A. Ragatz

$9.75, 567 pages

The fundamental principles of thermodynamics are presented in generalized form, with application to the compression and expansion of fluids, power generation and refrigeration.

The application of these principles are also applied to the calculation of equilibrium composition in both physical and chemical processes.

Standard Plant Operator's Questions and Answers —Vol. II

By Steve Elonka and Joseph F. Robinson

$8.00, 255 pages

The subjects covered by this very comprehensive book includes diesels, air conditioning, fuels and firing, compressed air, heat exchangers, gas turbines, cooling towers, building heating lubrication, nuclear power and safety.

A table of U. S. and Canadian engineers license requirements is also included.

This is a well written volume for those about to apply for operating license and would be a good addition to any operating engineer's library.

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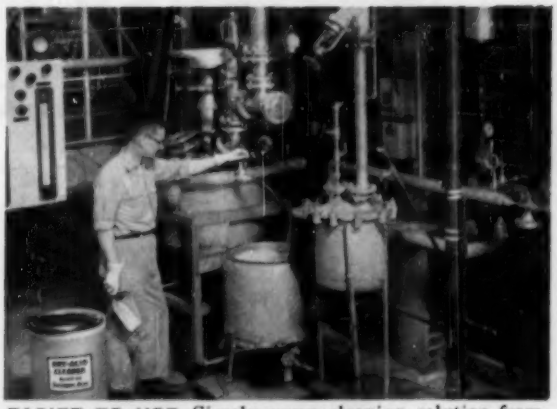

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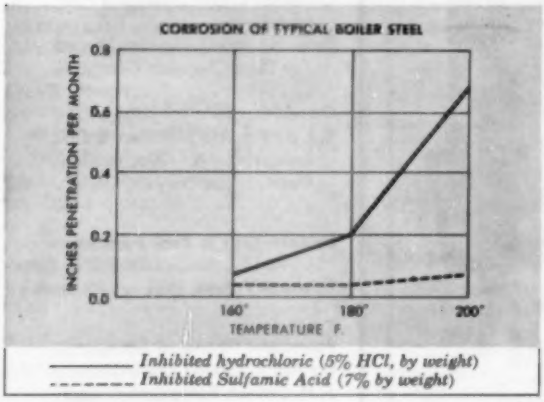

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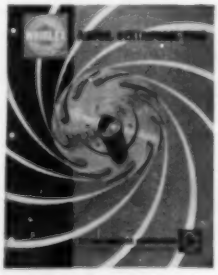

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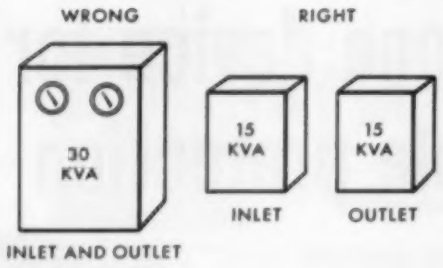
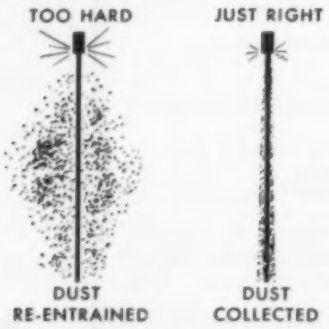
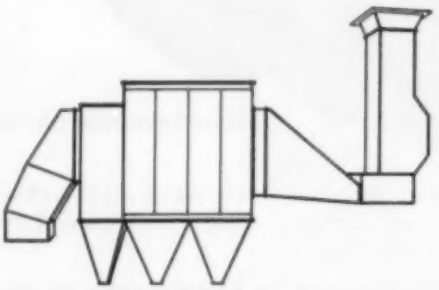


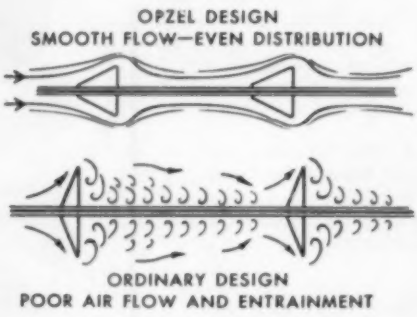
1. Electrical Sets should be arranged and rated to suit best the requirements of a specific job. Since electrical conditions can vary widely at different parts of the precipitator, it is good design to include several electrical sections in series, energized from separate sets so that each section may be energized as needed. Sets should be sized according to the amount of power the precipitator can absorb. A large excess of installed power, which will never be absorbed, means inefficient use of its equipment.



3. Rapping Intensity. Rappers should have easy means to vary the intensity of the blow to suit variations in operating conditions. A pre-set intensity setting cannot possibly give proper rapping over the normal range of operation. If too soft, build-up will occur which will disturb electrical conditions. If too hard, there will be reentrainment. Means of intensity adjustment are necessary to avoid drop-off of precipitator efficiency as conditions change.



2. Gas Distribution. Remember that gas distribution, gas baffling, and provision against hopper sweeping all have a large influence on collection efficiency. The gas flow system should be analyzed as closely as possible, both in the precipitator and in the associated duct-work. If in doubt, have a three-dimensional gas flow study made. Two-dimensional gas flow studies *are not as accurate* and may lead to erroneous conclusions.



4. Baffle Design. Careful attention to the design of baffles on the collecting plates is most important. Small amounts of reentrainment mean tremendous differences in over-all collection efficiencies. It is seen that the "quality" of the collecting surface is far more important than quantity—quantity (sq. ft. of surface or treatment time) in itself is not a criterion of performance.

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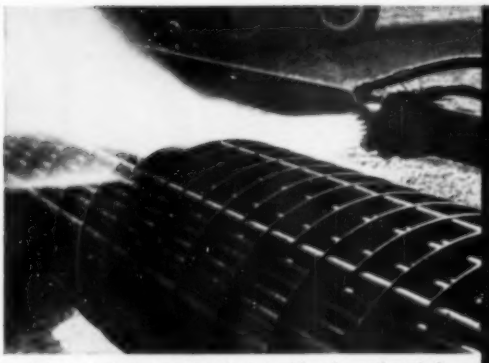
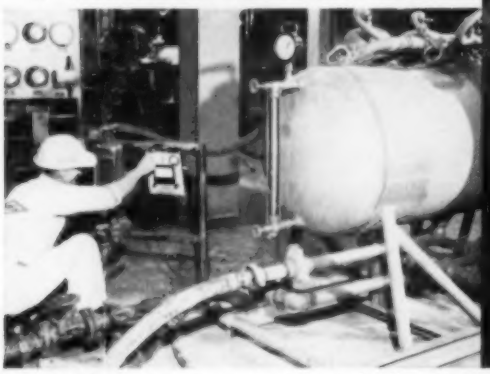
A new mark for a nation-wide cleaning service . . . DOW



Jetting tool cleans tubes fouled with coke and asphalt.



New mobile foam-cleaning equipment cuts cleaning costs.

Cleaning missile lines and components requires tolerances as close as 150 microns.

DOW INDUSTRIAL SERVICE

Industrial Cleaning. Dow Industrial Service, now a separate division of The Dow Chemical Company, offers the only nation-wide chemical cleaning service for virtually all types of industrial processing equipment. This is an expansion of the cleaning service developed over the past 20 years. Dow is currently servicing entire plants as well as doing special cleaning jobs for both large and small companies.

Dow Industrial Service research in industrial chemical cleaning has developed specialized mobile equipment and techniques, some of which are pictured above. These highly efficient techniques are improving plant productivity and reducing equipment downtime in all industries using steam generators, condensers, heat exchangers, towers, water and product lines, water wells and tanks, or similar process equipment.

Product Sales and Service. The sale of specialized chemical products, scientifically formulated to be of use in specific industrial processes and to give the necessary technical service in their use, is the job of Product Sales and Service. Purifloc* N17 is an outstanding new flocculant cleared by USPHS for use in potable water.

Laboratory Service. Because of the rapid development of chemical products for the municipal and industrial waste and water treatment areas, Dow Industrial Service will take on the service-selling of those products. Also, a consulting laboratory service for municipal and industrial waste and water treatment is provided.

You'll find Dow Industrial Service offices and stations with specialized cleaning equipment and experienced personnel in all major industrial areas. For more information, write to Dow Industrial Service, 20575 Center Ridge Road, Cleveland 16, Ohio.

*TRADEMARK

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